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THE ROYAL AERONAUTICAL SOCIETY

JULY 1961

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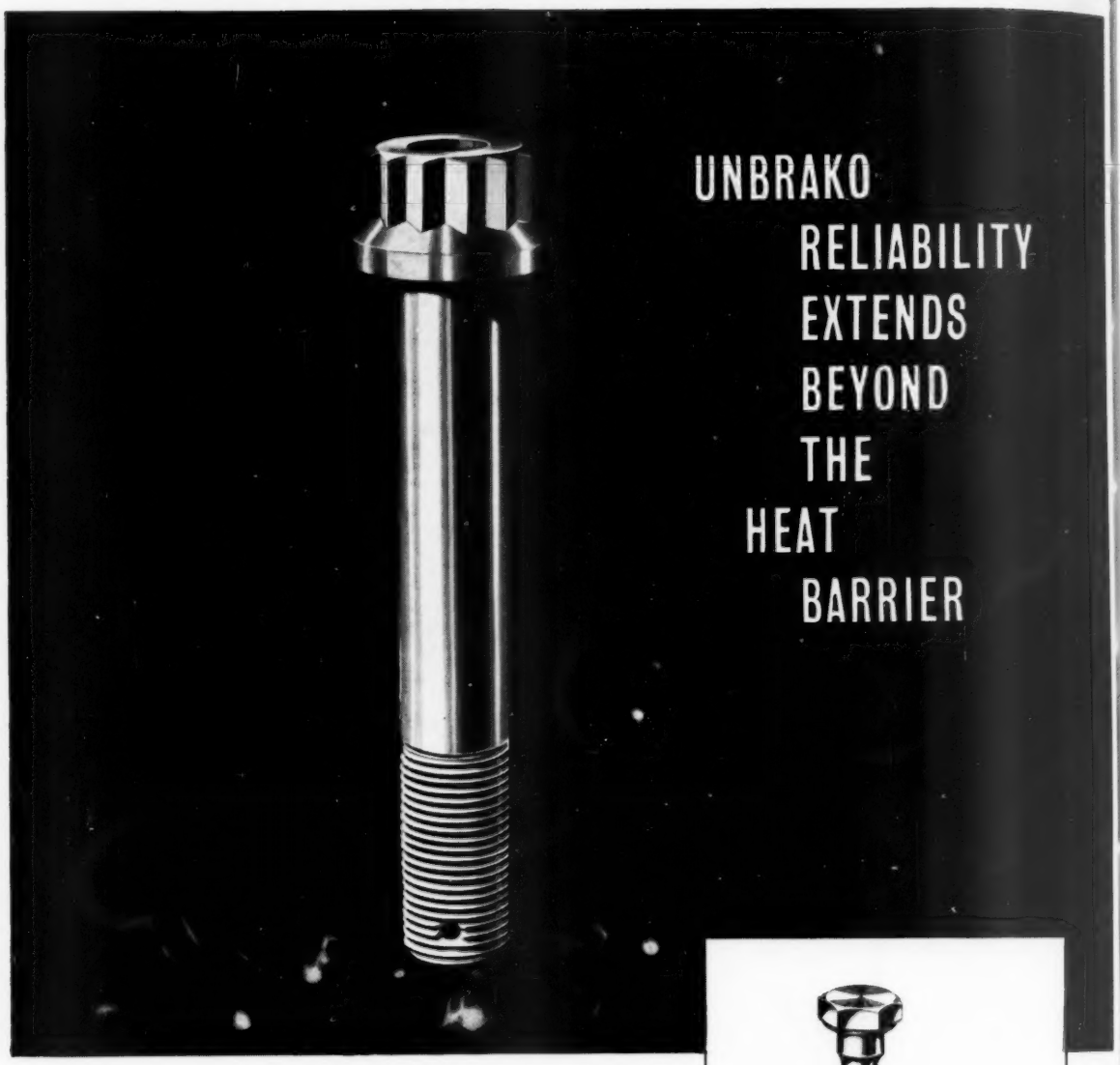

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Journal of
THE ROYAL AERONAUTICAL SOCIETY

INCORPORATING THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

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None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

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(Founded 1866)

Patron: Her Majesty The Queen

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Note: Under the revised By-Laws, allowed on 11th January 1960, the President of each Division and the Chairman of each Section of the Society is a Member of Council by reason of his office.

NOTICES

August Bank Holiday

The Offices of the Society will be closed from Friday afternoon, 4th August, until 9 a.m. on Tuesday 8th August.

Associate Fellowship Examinations, December 1961

The closing date for Candidates in the United Kingdom for the December 1961 Examination is 31st August. Entry forms may be obtained from the Secretary. The closing date for entries outside the United Kingdom was 30th June.

Annual General Meeting—4th May 1961

The Annual General Meeting of the Society was held in the Lecture Theatre at 4 Hamilton Place, W.1, on the 4th May 1961.

The President, Dr. E. S. Moult, presented a number of prizes and awards for papers published by the Society during the past year (*see* page xxviii, June Journal 1961).

The Annual Report and Balance Sheets of the Royal Aeronautical Society and Aeronautical Trusts Limited for 1960 were approved.

A number of members commented on the preparation of the Ballot Paper under the new By-Laws, thus preventing the election of more than one Associate Fellow at this election. The President pointed out that there was nothing to prevent the Members from electing as many Associate Fellows as they wished, provided there were at least ten Fellows and one Associate on the Council. This was entirely a matter of proposing Associate Fellows, and voting for them. It was agreed that this matter be drawn to the attention of the Members towards the end of the year.

The Secretary read out the names of the Members newly elected to the Council. These were:—

Professor J. A. J. Bennett
*Major G. P. Bulman
Mr. E. B. Dove
*Sir George Gardner
Mr. W. H. Stephens
Dr. E. W. Still
*Mr. T. A. Wolstenholme
*Re-elected.

The retiring President, Dr. E. S. Moult, handed over the Presidential Badge to the incoming President, Air Marshal Sir Owen Jones.

Dr. Moult was presented with a shield showing the Society's crest and recording his term of office. Dr. Moult was also presented with the original painting of the Lecture Theatre.

Note. Professor Bennett has been a member of Council for the past year as Chairman of the Rotorcraft Section. He is now a Member in his own right—the right of election by the Society Members. In the June Journal he was incorrectly stated to have been re-elected.

Birthday Honours List, June 1961

The President and Council congratulate the following members who were included in the Birthday Honours List:

K.C.V.O.	Basil Smallpeice (*Companion*)
C.B.E.	F. W. Page (*Fellow*)
C.B.	Air Vice-Marshal B. A. Chacksfield (*Associate Fellow*)
	Air Vice-Marshal T. U. C. Shirley (*Fellow*)
O.B.E.	R. A. Cocke (*Associate Fellow*)

Election of President-Elect and Vice-Presidents

The following were elected Office Bearers at the Council Meeting held on 25th May 1961:—

President-Elect:	Mr. B. S. Shenstone
Vice-Presidents:	Professor A. R. Collar
	Mr. H. H. Gardner
	Sir George Gardner

Eighth Anglo-American Aeronautical Conference, London, 3rd—14th September 1961.

Members are reminded that the closing date for registration for the Anglo-American Conference is 31st July 1961. The provisional Conference programme was published in the June "Journal" (page xxix) and an application form for registration was enclosed with the May "Journal." Members may obtain additional forms from the Secretary.

A special programme of visits and entertainment during the Conference is being arranged for ladies accompanying delegates from the United States and Canada. It is hoped that British delegates will bring their ladies to the Conference and that they will also take part in this programme.

Particulars of the social events during the Conference and the Ladies' programme will be sent to all those who have registered, later this month.

Lecture by Dr. Dobrov, U.S.S.R.

Dr. Dobrov, Chief Scientist of the Astronautics Society of the U.S.S.R., will be in London between the 7th and 15th July. During this time it is hoped that he will give a lecture to the Society on "Spacemen and Space Neighbours of the Earth." Unfortunately it was not possible to fix the exact date before the Journal went to press, but posters will be published and the press will be informed of the date and time.

Fellowship

The following have been elected to Fellowship:—

Jean Marie Rene Brocard, Director General, Société d'Etudes de Soufflerie Supersoniques pour L'Industrie Aéronautique, Paris.

Arthur Joseph Kenneth Carline, Chief Designer, Hunting Aircraft Ltd., Luton.

Eric Bairstow Carter, Director of Engine Production, Ministry of Aviation.

Robert Cockburn, Chief Scientist, Ministry of Aviation.

Peter Thomas Fink, Professor Mechanical Engineering, University of Sydney, Australia.

John Charles King, Manager, Aircraft Equipment Division, English Electric Co. Ltd., Bradford.

Geoffrey Michael Lilley, Deputy Head, Dept. of Aerodynamics, College of Aeronautics, Cranfield.

David Ronald Newman, Chief Aerodynamicist, de Havilland Aircraft Co. Limited, Hatfield.

Rotorcraft Annual Dinner

The Rotorcraft Section Annual Dinner will be held on Wednesday, 6th September, at the Dorchester Hotel. Reception 7.45 p.m. for dinner at 8.30 p.m. Full details will be sent to *Section Members* in July.

The Library

Will members please note that the Library will *not* be fully operative during the first fortnight of September while the Eighth Anglo-American Conference is being held.

Acknowledgments

The Council wishes to thank L. S. Armandias, Esq., *Associate Fellow*, for the gift of books and back numbers of *Aviation Studies Publications*.

The Council also thanks B. S. Franz, Esq., Beaumont, Chorleywood Road, Rickmansworth, for a collection of pre-1914 postcards of aeroplanes and their pilots—chiefly of Pégoud.

The Council also thanks Air-India International for the gift of six Commemorative Airmail Covers, three flown each way on the Inaugural Flight of the Boeing 707 Bombay-Nairobi.

W. J. Goodey, *Fellow*.

His many friends in the Society will learn with regret of the sudden death on 24th May 1961, of Mr. W. J. Goodey, *Fellow*, at Stroud, Glos. Mr. Goodey had contributed a number of papers and Technical Notes to the Journal, his last being in the May issue.

Rotorcraft Section Helicopter Rally and Garden Party

Once again the Rotorcraft Section are indebted to Mr. and Mrs. Charles Hughesdon for their kindness and generosity in acting as host and hostess of the Rotorcraft Section Helicopter Rally and Garden Party which was held on Saturday, 17th June 1961, at Ripley.

Unfortunately the weather was grey and dull, which deterred quite a number of people who had planned to attend. A record number of helicopters flew in—seventeen in all. Twenty-two had been expected, but bad weather grounded the Central Flying School party. Eleven types of aircraft were represented, including the new Hiller E4, the Sikorsky S-62, and the Wessex and Belvedere.

Joy-rides were again a popular feature; flying arrangements were efficiently organised by Captain David Eastwood, of B.E.A., and Shell-Mex and B.P. Ltd. provided refuelling facilities.

The President and Council of the Society wish to thank Mr. and Mrs. Hughesdon, the Ministry of Aviation, the Air Ministry and the Royal Air Force, the Army Air Corps and all those firms and individuals who contributed so generously with their aircraft, services and time, to this annual event of the Rotorcraft Section.

Second International Conference on Stress Analysis

The Joint British Committee for Stress Analysis (of which the Society is a member) announces that the Second International Conference will be held in Paris from 10th-14th April 1962. The Conference will be organised by Groupment pour l'avancement des Methods d'Analyse des Contraintes (GAMAC) and the three official languages will be English, French and German.

It is not intended to include review papers in the Conference and contributions will deal mainly with the results of experimental work. Prospective authors should submit a two-page abstract of their proposed paper together with a ten-line (maximum) summary not later than 30*th September* 1961. Authors will be told whether or not their papers are accepted by 15th November 1961. The Proceedings of the Conference will contain only the abstracts and summaries and authors will be free to arrange publication of their complete papers after the Conference.

The proposed Registration fee is 60 NF, which will include a set of the summaries of the papers.

Registration forms and further information may be obtained from The Secretary, The Joint British Committee for Stress Analysis, The Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1, to whom abstracts and summaries of proposed British contributions should also be sent.

Elections

The following is a list of elections and transfers of membership of the Society:—

Associate Fellows

George Frederick Ackroyd (*from Graduate*)
Alfred William Bedford (*from Associate*)
Peter Charles Berryman (*from Associate*)
Jack Blanchard-Sims
Elio De Sabata (*from Graduate*)
Ian Stuart Donaldson
Hubert Kelsey Gordon-Burge (*from Associate*)
Kenneth George Harold
John James Simpson Hirons
Dennis Anthony Howard (*from Graduate*)
Peter Frederick Jowitt (*from Graduate*)
Stanley McCreith
Ernest Capel Martin (*from Student*)
Bertram Arthur Morris (*from Associate*)
Alastair Panton
Hugh Trounce Pascoe (*from Associate*)
Alan Peacock
Fredrick Henry Pierce
Noel Edward Lyle Rossiter
Ernest John Sandoe (*from Graduate*)
John Ernest Dudley Scott (*from Associate*)
Alfred George Leslie Standley (*from Associate*)
Roslyn Swinburne Trayford
Gordon Cecil Turner
Joseph Leslie Uncles

Associates

Malcolm John Beaton
Robert Brown (*ex Associate*)
Ronald Chippindale
Ronald Arthur Cox
Arthur Golding-Barrett
Cyril Benjamin Hill
Ronald Hirst
Stephan Kock
Peter Mills
Cecil Berry Ottaway
Allen William Page
Kenneth Francis Patten
Maurice John Phillips
Ronald Gordon Simmons

Graduates

Robert William Bilger
Peter Leonard Duffield (*from Student*)
Nigel John Field-Richards
John Charles Fincher (*from Student*)
Edwin John Hearn (*from Student*)
Anthony Hedges
Graeme Donald Hollyman
Frank Howie
Katta Krishnamurthy (*from Student*)
Stuart Vincent Molony (*from Student*)
Ian Thomas Nicoll (*from Student*)
Walter Cyril Parson
Michael Alan McEwen Pirie
John Christopher Adams Plaskett
Colin William Spitzkowsky
David Hugh Tipper (*from Student*)
Clifford Mark Voisey
James Martin Walker
David Sapwell Woodward (*from Student*)

Students

Venkatrama Iyer Kalyana Raman
Peter James Schofield
Kushal Pal Singh
Brian Mervyn Taylor
Derrick Geoffrey Welch

Companions

Ernest Barton
Edgar Alexander Bell
Gareth Mervyn Hamilton-Fletcher

Waverley Gold Medal and Essay Competition 1961

Research is again sponsoring this competition to encourage scientists to write clearly and comprehensibly. The Medal, together with £100, will be awarded for the best essay of about 3,000 words describing a new project or practical development in pure or applied science. Further details and entry forms may be obtained from the Editor, *Research*, 88 Kingsway, W.C.2.

Short Vacation Course in Meteorology: 6th-13th September 1961

This course will be held under the auspices of the Field Studies Council and the Royal Meteorological Society at the Malham Tarn Field Centre, Yorkshire, from 6th-13th September 1961. The course is suitable for undergraduates in physics, mathematics, geography; for teachers, keen amateur meteorologists and Service Personnel. The inclusive fee is £8 0s. 0d. Applications and enquiries should be addressed to: The Warden, Malham Tarn Field Centre, near Settle, Yorkshire.

News of Members

R. D. Boot (*Associate Fellow*) has been appointed Assistant Flight Test Manager of Blackburn Aircraft Ltd.

M. J. Brennan (*Fellow*) formerly Director and Chief Engineer, Folland Aircraft, has been appointed Chief Engineer (Aircraft) of A. V. Roe Ltd.

M. G. K. Byrne (*Associate Fellow*) formerly Public Relations and Publicity Manager, has been appointed Sales Manager of Blackburn Aircraft Ltd.

A. L. Cattermull (*Associate*) formerly A.I.D., Central Headquarters, Chessington, is now P.I.(A), North Midland A.I.D. Region.

G. C. Cook (*Graduate*) formerly in the Advanced Projects Group of Hawker Siddeley Aviation, is now a Senior Engineer with Microcell Ltd.

J. R. Cownie (*Graduate*), formerly Assistant to the Technical Editor "The Aeroplane and Astronautics." has been appointed Assistant Press Officer, Rolls-Royce Ltd., Derby.

A. M. Cundick (*Graduate*) formerly Aerodynamics Group Leader with Folland Aircraft Ltd., Hamble, is now Head of Flight Performance and Handling Department, Short Bros. and Harland Ltd., Belfast.

Sqn. Ldr. R. A. Cunningham (*Associate Fellow*) formerly Missile Servicing, R.A.F., Hemswell, is now at H.Q. Bomber Command (Sigs. 3) High Wycombe.

Flt. Lt. K. F. Currey (*Associate Fellow*) formerly Officer Commanding Ground Radio Servicing Flight, R.A.F., Marham, is now with No. 3 Maintenance Unit, R.A.F., Akrotiri, Cyprus.

G. M. Dickson (*Associate*) formerly Regional Representative, Uganda, of the East African Directorate of Civil Aviation is now the Chief of Air Navigation Services of the Directorate in Nairobi.

R. A. V. Dismore (*Associate Fellow*) formerly Engineering Technical Services Manager, B.O.A.C., has been appointed Chief Production Engineer.

G. E. Dixey (*Student*) formerly Engineer, Elliott Bros. (London) Ltd., is now Senior Research Engineer, Amplivox Ltd., Wembley.

Sir George Edwards (*Honorary Fellow*) has been appointed a Director of British Aircraft Corporation (Australia) Pty., Ltd.

K. Essex-Crosby (*Associate Fellow*) has been appointed Flight Test Manager of Blackburn Aircraft Ltd.

A. H. C. Greenwood (*Associate Fellow*), Chairman of the Aircraft Sales Committee of British Aircraft Corporation and Sales Director of Vickers-Armstrongs (Aircraft) Ltd., has been appointed a Vice-President of British Aircraft Corporation (U.S.A.) Inc.

Wing Cdr. T. E. Guttery (*Associate Fellow*) has retired from the Royal Air Force. He was formerly statistical officer at Royal Air Force College and Bomber Command.

Commander T. G. F. Hardy (*Associate Fellow*), R.N., formerly Engineer Officer-in-Charge, R.N. Aircraft Workshops, Almondbank, is now in Flight Deck Machinery Development, R.A.E., Bedford.

Commander S. C. Haynes (*Associate Fellow*), R.N., formerly Development Project Officer in the Ministry of Aviation, is now with British Defence Services, Washington.

D. M. Heughan (*Associate Fellow*) has resigned from the de Havilland Aircraft Co. Ltd., and is now with Associated Industrial Consultants Ltd.

W. A. Kuipers (*Associate Fellow*) formerly Chief Engineer, Nederlands Helicopter Industrie N.V., is now with the Bell Helicopter Company, Fort Worth.

B. P. Laight (*Fellow*) previously Director and Chief Designer of Blackburn Aircraft Ltd., now becomes Director and Chief Engineer.

Capt. E. D. G. Lewin (*Associate Fellow*) previously Joint Managing Director of Blackburn Aircraft Ltd., becomes Managing Director.

M. A. Maller (*Associate Fellow*) formerly member of International Marketing Staff, Texas Instruments Inc., Dallas, U.S.A., is now Manager, Geneva Branch, Texas Instruments International Limited.

J. Meadows (*Associate Fellow*) formerly Senior Aerodynamicist has been appointed Chief, Aerodynamics Department with Gloster Aircraft Co. Ltd.

R. J. Monaghan (*Fellow*) formerly Superintendent, Hypersonics Division, R.A.E., is now Assistant Director (Aircraft) on the Defence Research Staff, British Embassy, Washington.

E. B. Moss (*Fellow*) formerly P.S.C. Applied Research Ltd., Ontario, is now Senior Staff Engineer, Douglas Aircraft Company Inc., Missiles and Space Systems.

Sqn. Ldr. W. Muirhead (*Associate Fellow*) formerly O.C. General Engineering Squadron Maintenance Base, R.A.F. Seletar, Singapore, is now at A.W.R.E., Aldermaston.

Sqn. Ldr. J. S. Newman (*Associate Fellow*) has retired from the R.A.F. and is now an Engineer with E. S. & A. Robinson of Bristol.

W. A. Pennington (*Associate Fellow*) formerly Chief Project Engineer, English Electric Aviation Ltd., is now Chief Engineer, Hovercraft Development Ltd.

R. H. Platt (*Associate Fellow*) formerly a Senior Stress Engineer with Microcell Ltd., is now Chief Stressman with White and Riches Ltd.

C. W. Prower (*Fellow*) has been appointed Chief Project Designer of Blackburn Aircraft Ltd.

K. D. Raithby (*Associate Fellow*) formerly Fatigue division, Structures Department, R.A.E., Farnborough, is now Structures Representative, Aircraft Branch, Defence Research Staff, British Embassy, Washington.

T. H. Robjohn (*Associate Fellow*) formerly Section Leader, Staverton (Engine) Repair Section is now Repair Designer of the Staverton (Engine) Division of Dowty Rotol Ltd.

N. E. Rowe (*Fellow*) has relinquished his appointment as Joint Managing Director of Blackburn Aircraft Ltd, to become a full-time Director of Hawker-Siddeley Aviation.

H. D. Ruben (*Associate Fellow*) formerly Chief Aerodynamicist, M.L. Aviation Co. Ltd., White Waltham, is now Chief Aerodynamicist with British Executive and General Aviation Ltd., Shoreham.

Sqn. Ldr. R. E. Sharrock (*Associate Fellow*) formerly Engineer Officer No. 64 Squadron, R.A.F. Duxford, has been posted to R.A.F. Tengah, Singapore, for Technical Duties.

Flt. Lt. B. D. Smith (*Associate Fellow*) has completed No. 3 Advanced Armament Course at the R.A.F. Technical College, Henlow, and is now with the Armament Department, R.A.E., Farnborough.

Sir Reginald Verdon Smith (*Companion*) has been appointed a Director of British Aircraft Corporation (Australia) Pty., Ltd.

W/O M. Sparks (*Associate*) formerly with 230 O.C.U., R.A.F., Waddington, is now at Technical Wing H.Q., R.A.F., Khormaksar.

J. T. Stamper (*Associate Fellow*) has been appointed Chief Designer (Buccaneer) of Blackburn Aircraft Ltd.

Colonel H. L. W. Stevens (*Associate Fellow*) formerly Technical Expert (Supplies) Iraqi Republican Railways & Airways, Baghdad, has joined the Ghana Civil Service as Chief Stores Superintendent, Ghana Railway & Harbours in Sekondi, Ghana.

P. Thompson (*Graduate*) formerly Technician A. V. Roe and Co. Ltd., Manchester, is now Assistant Factory Manager, Goss Printing Press Co. Ltd., Preston.

Sqn. Ldr. W. Warhaftig (*Associate Fellow*) formerly at H.Q., No. 23 Group is now O.C. Air Engineering Squadron, R.A.F., Bassingbourn.

Dr. E. J. Warlow-Davies (*Fellow*), Chief Engineer (Aero) and a Special Director of Bristol Siddeley, has been appointed a Director of Bristol Siddeley's Main Board.

J. A. C. WILLIAMS (*Associate Fellow*) Principal of the College of Aeronautical Engineering has been appointed Director of the Aeronautical Education Trust Ltd.

R. G. WILLIAMSON (*Graduate*) having completed his apprenticeship with Bristol Aircraft Ltd., is now a Junior Research Officer, Mechanical Engineering Division, National Research Council of Canada.

A. WILSON (*Associate Fellow*) formerly R.T.O. at Saunders-Roe Helicopter Division has been transferred to the Airborne and Helicopter Division, A. & A.E.E., Boscombe Down.

Group Captain W. G. WOODWARD (*Associate Fellow*), Vice-President of the New Zealand Division for the past two years, has been transferred to The Royal New Zealand Air Force Liaison Office in London.

CHANGES OF ADDRESS OR APPOINTMENT

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address. He would also like to know of any change of appointment.

When notifying changes please give the following particulars:—

Name (in block letters) Grade of Membership
New Address (in block letters) Old Address

New appointment.—Please give name and address of employer and position held, and former appointment.

Changes of address must be received *before the 15th of the month* in order to be effective for the following month's JOURNAL.

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THIRD INTERNATIONAL SYMPOSIUM ON RAREFIED GAS DYNAMICS—1962

This symposium will be held at the University of Paris, 26th-29th June 1962.

The programme will range from topics of immediate significance for upper atmosphere and space flight to basic scientific studies and will include the following: Studies of the limits of the continuum theory or the quasi-equilibrium kinetic theory of gases; Problems in kinetic theory of gases, particularly attempts to solve the Boltzmann equation; Free-molecule and near-free-molecule flow in neutral and ionised gases; The physics of surface interactions between gases and solids; Boundary conditions for rarefied gas equations—Slip flow; Experimental techniques and instrumentation developments bearing on the above, whether applied to laboratory or field experiments.

Inquiries from Europe should be addressed to Laboratoire d'Aerothermique, 4c, route des Gardes, Meudon (S & O), France, and from the U.S. to L. Talbot, Department of Aeronautical Sciences, University of California, Berkeley.

INTERNATIONAL CONGRESS OF AVIATION AND COSMONAUTICAL MEDICINE

The International Congress of Aviation and Cosmonautical Medicine will be held in Paris from 26th-30th September 1961. The main topics to be discussed will be: (*i*) Psychophysiological problems raised by professional adaptation or inadaptation in the aviation environment. (*ii*) Physiopathological problems in relation to modern aircraft flights and recent physiological researches on Cosmonautics. (*iii*) Forentsic medicine problems applied to aviation. (*iv*) Professional pathology of flying personnel in charge of flight safety. There will be a special progtramme for ladies accompanying delegates.

Registration fees, which include a reception, final banquet, laboratory visits, cocktail and evening parties, and copies of the papers presented are: Delegates—"active members"—60 N.F. Associated members (members of a delegate's family) 20 N.F. Full particulars may be obtained from: Secretariat Général du Congrès International de Médecine Aéronautique et Cosmonautique, C.E.R.M.A. 5 bis Avenue de la Porte de Sèvres, Paris XV°, France.

BOOKS *OF INTEREST TO AERONAUTICAL SCIENTISTS*

Advances in Space Science and Technology

Edited by FREDERICK I. ORDWAY, III., *George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama*

Volume 1, *1959, 412 pp., 86s.*

Volume 2, *1960, 450 pp., 93s.*

Volume 3, *1961, about 485 pp.*

Reviews of Volume 1:

"The articles are written in a factual straightforward manner, with obvious technical competence. An appendix is included that provides an idea of the number of areas from which the body of knowledge of astronautics is being assembled. Fields of interest to personnel in the astronautical sciences are listed for literature classification purposes."

—IRE Transactions on Human Factors in Electronics.

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Edited by LOREN E. BOLLINGER, MARTIN GOLDSMITH *and* ALEXIS W. LEMMON, JR.

A Selection of Technical Papers based mainly on a Symposium of the American Rocket Society held at The Ohio State University, Columbus, Ohio, July 18, 19, 1960.

December 1960, 682 pp., 52s.

Volume 3: Energy Conversion for Space Power

Edited by NATHAN, W. SNYDER

A Selection of Technical Papers based mainly on a Symposium of the American Rocket Society held at Santa Monica, California, September 27-30, 1960.

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Volume 4: Space Power Systems

Edited by NATHAN W. SNYDER

A Selection of Technical Papers based mainly on a Symposium of the American Rocket Society held at Santa Monica, California, September 27-30, 1960.

June 1961, 632 pp., 48s.

Volume 5: Electrostatic Propulsion

Edited by DAVID B. LANGMUIR, ERNST STUHLINGER *and* J. M. SELLEN, JR.

A Selection of Technical Papers based mainly on a Symposium of the American Rocket Society held at Monterey, California, November 3, 4, 1960.

June 1961, 579 pp., 46s.

Methods of Celestial Mechanics

By DIRK BROUWER, *Yale University*
and GERALD M. CLEMENCE, *United States Naval Observatory*
June 1961, 598 pp., 111s.

This book, by two of the world's most distinguished astronomers, provides much information needed in our exploration of space.

An Introduction to Astrodynamics

By ROBERT M. L. BAKER, JR.,
and MAUD W. MAKEMSON, *University of California at Los Angeles*
1960, 358 pp., 60s.

The book will serve as a textbook for introductory undergraduate courses and as a reference and handbook of astrodynamical techniques for engineers and scientists involved in space technology.

Gyrodynamics and its Engineering Applications

By RONALD N. ARNOLD *and* LEONARD MAUNDER,
University of Edinburgh
August 1961, about 500 pp., approx. 100s.

This book presents an account of basic theory, together with a detailed study of gyrodynamics in machines and in modern gyroscopic devices. Some sections have been developed by the authors and are not to be found in other publications.

Introduction to Hypersonic Flow

By C. G. CHERNYI, *Moscow State University*
Translated and Edited by RONALD F. PROBSTEIN,
Brown University and Avco Research Laboratory
September 1961, about 200 pp.

This translation of a Soviet text used at Moscow University provides an introduction to the fundamentals of inviscid hypersonic flow theory and to the most important methods of calculating ideal gas flows at hypersonic speeds. Included are many topics to which Soviet aerodynamicists and the author, in particular, have made major contributions and which are not to be found discussed in detail in Western books on the subject.

Hypersonic Flow Theory

By WALLACE D. HAYES, *Princeton University and Space Technology Laboratories, and* RONALD F. PROBSTEIN,
Brown University and Avco Research Laboratory
1959 (Second printing 1961). 474 pp., 82s.

"There is not room here for an enumeration of the many original and previously unpublished contributions of both authors. No other book on hypersonic flow is likely to supersede this one for quite a few years."

—Mathematical Reviews.

Rarefied Gas Dynamics

Proceedings of the Second International Symposium held August 3-6, 1960, University of California, Berkeley

Edited by L. TALBOT, *University of California, Berkeley*
September 1961, about 750 pp.

Supplement 1 of
Advances in Applied Mechanics

The forty-one papers contain contributions to the subjects of kinetic theory, high altitude hypersonics, free molecular flow, gas-surface interactions, and low density ionized gas phenomena.

Combustion, Flames and Explosions of Gases

By BERNARD LEWIS *and* GUENTHER VON ELBE,
Combustion and Explosives Research, Inc., Pittsburgh
Second Edition, July 1961, 731 pp., 157s. 6d.

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—Journal of the American Chemical Society.

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The Journal of the Royal Aeronautical Society

INCORPORATING THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

VOLUME 65 JULY 1961 NUMBER 607

The Law versus Science in Aeronautics

BY

H. CAPLAN, D.C.Ae., A.F.R.Ae.S., A.M.I.Mech.E.

(Assistant Secretary, British Aviation Insurance Co. Ltd.)

The 1,183rd lecture to be given before the Society, "The Law Versus Science in Aeronautics," was given by Mr. H. Caplan, D.C.Ae., A.F.R.Ae.S., A.M.I.Mech.E., British Aviation Insurance Co. Ltd., in the Lecture Theatre on 12th January 1961—the 95th Anniversary of the founding of the Society. Mr. Walter Tye, O.B.E., B.Sc., F.R.Ae.S., Member of Council and Chief Technical Officer, Air Registration Board, took the Chair. Introducing the lecturer, Mr. Tye said that this was an unusual subject for this Society, which was predominantly scientific, but he could guarantee, having known the lecturer for a long time, that he would make it interesting.

It was a pleasure to him to introduce Harold Caplan, as he counted him as a friend. Mr. Caplan began his career in engineering as an aeronautical apprentice at Bristol's. He then went to the College of Aeronautics and he was the first of the ex-students of the College to give a Main Lecture before this Society, but what distinguished him from most of them in the Society was that he had also qualified as a Barrister at Law. For 11 years or so he had been with the British Aviation Insurance Company, where he initially dealt with engineering matters, accidents investigation, claims, analysis of risk and so on: but more recently, with his added facility in the subject of law, he had been responsible for legal advice in his company. He was for a period, the Chief Technical Officer of the Company and he was now the Assistant Secretary. With his combined background of engineering science and law they could have no more suitable lecturer for the subject that evening.

SUMMARY: Law, Science and Aeronautics are defined in broad terms and some landmarks are outlined in the history of control of aeronautics by legal means.

The exercise of national sovereignty often means that relevant laws are a serious limiting operational parameter. This and other factors may hinder the development of international air transport (especially supersonic aircraft) and may thus threaten the livelihood of aeronautical scientists.

When aviation accidents occur, the operation of rules which determine "legal liability" may thrust an unfair financial burden on sections of the community which may be blameless from a scientific point of view. Suggestions for the future are made.

Scientific exploration into outer space provides a crucial opportunity for the nations of the world to co-ordinate the disciplines of science, law and politics in a way never before possible. Members of the Royal Aeronautical Society cannot afford to ignore this challenge and a practical suggestion is made as a first step in implementation.

1. Introduction

1.1. GENERAL METHOD AND OBJECTIVES

This paper is designed to persuade members of the Royal Aeronautical Society that they have a vital part to play in moulding the future laws of aeronautics. The practice of law is very properly left to lawyers, and this paper will be of little interest to the professional lawyer. It attempts to be neither scholarly nor objective. It is a ruthlessly personal plea to the Society to find ways of harnessing the scientific method in the service of aeronautical law-making—based on the conviction that unless this is done, aeronautical activity will remain a blind technological tool of an imperfect civilisation.

Only a few years ago, Prof. Dr. Goedhuis reminded us[1] that in 414 B.C. Aristophanes in his play *The Birds* dramatised the unwelcome attentions of legislators in aerial activities when he portrayed the birds building their ideal city in the clouds—Nephelococcygia—the original cloud-cuckoo-town—they had to repulse a town-planning expert, an inspector and a law maker! Dr. Goedhuis comments that Aristophanes could pride himself on his foresight if only he could "see in what measure the legislators have prevented the birds of this day from unfolding their wings."

Aeronautics as we understand it is, of course, relatively recent in origin. Nevertheless an historical approach will be used—as being a convenient and dramatic way of illustrating truth or absurdity. An historian may complain that the text which follows is somewhat erratic: it will leap from the distant past to the unknown future. This too seems necessary. Only from a comfortable distance is it possible to view the spectacle of history. The recent past is too embarrassingly close to be the subject of reasonable judgment. Yet it is only from the perilous present that the shape of the past may be projected as an image of the future.

1.2. DEFINITIONS

Some broad definitions are necessary of the terms used in this discussion:

"THE LAW" may be defined as those rules of human conduct which are ultimately enforceable in civil courts of law. More specifically this paper is based on English law, with some cautious deferential reference to North

1. "The Air Sovereignty Concept and United States Influence on its future development" (1955) 22 *J. of Air Law & Commerce* 2, 209.

American manifestations of what was once a common law. However, when considering early laws, pride of place has been given to some French rules—as befits the home of ballooning and logical legislation.

"SCIENCE" is understood to mean the whole body of organised knowledge of the physical world. In this sense it must range from physics and astronomy to applied technology.[2]

There will be no quarrel with the meaning of "knowledge" or the meaning of "meaning."

"AERONAUTICS" will be used to denote the present and future scope of activities with which the Royal Aeronautical Society is concerned. Therefore it will include, for example, not only airships, missiles, spaceships and satellites—but even aeroplanes. The Society clearly includes Astronauts as well as Aeronauts.

1.3. BASIC CONSIDERATIONS

As in school exercises, the task will be to 'compare and contrast' the separate disciplines of *law:* (man-made rules for men) and *science:* (man-discovered rules for man and the universe). In essence therefore this is a study of the contrast between the laws of men, and the laws of nature, a conflict familiar throughout human history.

It is first essential to realise that the rules of law are not necessarily logical. The state of the law at any given moment is the result of fitting together the multiple accretions of human rule-making—some of it in one century, some of it may be in another. Although the process of fitting the rules together may be logical, since the rules are not necessarily compatible one with the other, the result may often lack logic. For example the state of the law today on capital murder is a combination of the recorded views of judges in the middle ages and the views of Parliament (as expressed in statutes of the Realm) in this century. Lawyers are usually more concerned to know that the law is certain or ascertainable than that it should be logical or even just. If it is unjust, then it is the task of legislators to alter it.

Because it is usually necessary to consult a lawyer to know what the law is, lawyers are often left alone to give their views on what the law should be. This is an unfair task and may result in lawyers being made scapegoats for any unsatisfactory state of the law. Without external guidance, law reforms initiated solely by lawyers are apt to consist of the application of established legal principles to present affairs—whereas what may often be needed is *new principles* consistent with changes in the structure of civilisation.

Scientific or technical knowledge on the other hand must have a logical structure. Its hypotheses must be capable of being tested by observation or experiment. An hypothesis only has value so long as it is consistent with all available evidence and can be used as a basis for prediction.

Thus the law may be in a constant state of evolution towards the desirable regulation of human conduct as society sees it from time to time. At the basis of law is therefore human will and consent and it may represent a society's summation of scientific, political, economic and humane aspiration at any given moment.

The laws which science seeks to unravel are unalterable by human will or consent, and progress is marked by better and better approximations to the underlying rules of the natural universe.

If, therefore, the law is alterable by human will, then nothing should be easier than to alter illogical, unjust or repellant laws. Only perhaps in totalitarian dictatorships is this possible. In a complex democracy such as our own, changes of the law are deliberately made not only difficult but responsive to the will of the people.

In the argument which follows, an attempt will be made to describe some aeronautical activities in which future development may be stifled by inadequacies of the law. Not everybody's hobby-horse will be on view. But there may be enough to inspire members of this Society to play their part in avoiding future suffocation. In the long run, of course, scientific knowledge does permeate to the legislative levels. But the process is slow, it may be too slow for the future of aeronautics.

Those who agree with Henry Ford—that "history is bunk"—may wish to proceed direct to Section 3. "History," said one of James Joyce's characters, "is a nightmare from which I am trying to awake."

2. Some Early Laws and Regulations

2.1. THE GENERAL INTERACTION OF LAW AND SCIENCE

The way in which the scientific knowledge of an age gradually permeates to the level of everyday knowledge and awareness is not usually in the form of scientific theories, but more often in an acceptance of the technological applications of science for everyday use. Thus the ubiquitous 'man-in-the-street' need know nothing about aerodynamics, but he is content that an aeroplane is a man-made device and is not supernatural. This diffusion of science down to an everyday level then becomes part of his background of thought—which then must colour any consent which he gives to the society in which he lives. Since consent is at the basis of national and international law, it may be seen that there has been an *interaction* between science and the law throughout history.

For example in international law, at one time three miles (reputedly the limit of cannon-shot) seemed a reasonable limit for territorial waters whereas today the nations have great difficulty in agreeing upon a common horizontal limit for the exercise of their sovereign power over coastal waters: the reason is that there is now greater knowledge of what lies in the rocks under the sea, and greater knowledge of the conservation of ocean life and harvests. The scientific basis of consent has been altered.[3]

2.2. EXAMPLES OF EARLY REGULATION

Before any aircraft had flown, J. S. Danck in a thesis delivered in 1687 at Frankfurt,w rote on problems

2. The whole of applied technology, of course, is not necessarily scientific. *See* for example *Institution of Mechanical Engineers v. Cane* (a House of Lords decision), *The Times*, 23rd Nov. 1960, [1960] 3 W.L.R. 978.

3. Law and Science in the Space Age (1959) *J. of Business Law* 103—in which further examples are quoted.

in aeronautical law—*De jure principis in Aereo.*[4] However, few people would expect aeronautical legislation to be made before the advent of powered flight in 1903—and indeed it was not for another eight years that the *Aerial Navigation Act* 1911 became the law of England. This Act was passed because of fears that aircraft flying over large crowds (such as those which assembled for King George V's Coronation) might descend uncontrollably and generate death and destruction. The Home Secretary was therefore given powers to prohibit flying over any areas which he chose to prescribe for this purpose. The Aerial Navigation Act 1911 appears to have been the first national (as opposed to local) legislation anywhere in the world dealing with all types of aircraft. The first national legislation dealing with balloons appears to have been in Brandenburg, Prussia on the 10th August and 22nd October 1910.

In France, however, the home of hot-air ballooning, these same dangers had been appreciated 126 years earlier—following several forced landings in the Tuilleries and elsewhere. The first successful ascent of the Montgolfier balloon on 5th June 1783 was therefore followed by an order by the Chief of Police in Paris (dated 23rd April 1784) prohibiting the manufacture and use of balloons whose heating devices constituted a fire-hazard, and prohibiting any other balloon ascents without prior police permission—which would not be given unless appropriate precautions were taken. Disobedience was punishable by a fine. Since this is probably the first example of modern aeronautical legislation, the French text is shown in full in Appendix A.[5]

It is not too much to say that the pattern of control set by this early decree has been followed in virtually all forms of air navigation regulations subsequently all over the world in the interests of the innocent public:

First – the appreciation of present hazards
Second – the prohibition of foreseeably similar hazards
Third – permission to conduct related activities subject to the adoption of prescribed precautions
Fourth – contraventions are treated as criminal offences.

Each of the first three stages of this process depends vitally on the state of scientific (and the derivative technical) knowledge of the day. But once an outright prohibition is made, then all development in that direction almost inevitably ceases. It is fascinating to speculate what might have been the future course of hot-air balloons if safe forms of air-heating had been available. Even today, lighter-than-air gases are not cheap, and only helium is safe. It is doubtful whether the Paris Chief of Police in 1784 would have approved of our present aircraft designs—in which a raging furnace, encased by a burning hot stovepipe is often to be found in reasonable proximity to thousands of gallons of inflammable fuel.

Applicants for permission to take off in Paris had to show that they were persons of known experience and skill, and they had to specify the place, date and time of their proposed ascent. The penalty for disobedience to the decree was five hundred "livres"—which is believed to have been very heavy for that era.

The 1784 decree was not amended until 21st August 1819, when the Prefect of Police became more certain of what he would tolerate:[6]

(*i*) The use of Montgolfier balloons, and any others having a fire suspended beneath them was absolutely prohibited in all circumstances.
(*ii*) No lighter-than-air craft (aerostat) could take off without a parachute.
(*iii*) No ascents could be made after sunset, or before the harvests had been gathered in.

It is not clear whether the parachute was a device to arrest the fall of the complete balloon, or simply that of individual aeronauts. But the same theme is apparent—the prohibition of known hazards and the protection of the innocent public.

Although this appears to be simply the first ban on night *take-offs*, it was probably effective to curtail night operations due to the limited endurance of the early balloons. The Prefect of Police did not find it necessary to ban night landings.

Despite the pioneering efforts of France in aeronautical legislation, it was in America and not in France that the first regulations dealing with heavier-than-air craft appeared. It was not for lack of foresight that France delayed further legislation, *e.g.* in 1863, G. de Landelle[7] predicted the need to make regulations for the avoidance of aerial collisions—which is still a very topical subject! He thought that there would be three ways of avoiding collisions—to go in reverse, to go sideways, and to move up and down. He even formulated a forerunner of the modern quadrantal rule which was forgotten by later generations, and suggested that ascending aircraft should give way to descending aircraft. He suggested that clock towers should carry large weather-vanes to indicate wind-direction to aviators; he foresaw the need for fixed navigational lights and beacons, and lights on the aircraft for night-flying.

But the penal regulation of aviation was already an accepted idea. Writing in 1908, Henri Kistemaeckers[8] lightheartedly predicted that for aviators, the principal operating expense of the future would not be fuel, or wear on wings or guide-ropes but the cost of having to pay fines every time the aircraft descended unexpectedly at the feet of pedestrians and motorists!

The early regulations of Kissimmee City (Florida) display the alarming variety of regulations which can be conceived by a zealous public authority:

Be It Ordained by the Council of the Town of Kissimmee City:

SECTION 1

For the purpose of this ordinance, the boundaries of the airship limit of the town shall be to extend upward in a vertical direction for

4. *See* An Historical Survey of International Air Law before the Second World War by P. H. Sand, J. de S. Freitas and G. N. Pratt, Vol. 7. *McGill Law Journal* No. 1, January 1961.
5. As printed in *Le Code de l'Air* by Gaston Bonnefoy (Marcel Rivière, Paris 1909).
6. *See* Appendix A.
7. In his book *Aviation ou Navigation Aérienne sans ballons*, quoted by Bonnefoy, op. cit. p. 166.
8. *L'Auto*, 10th January 1908; quoted by Bonnefoy, op. cit. p. 161.

a distance of 20 miles in the sky; and the limit of the town shall be the same as that of the fire limit of the town.

SECTION 2

It shall be unlawful for any person, firm or corporation to keep an airship shed, barn or garage for the stalling or repairing of airships, or an airship station, depot or terminal for the shipment or discharge of freight or passengers within the airship limit without the permission of the council, which privilege shall be subject to revocation at any time upon six months' notice.

SECTION 3

Every person, firm or corporation keeping an airship shed, barn or garage shall pay an annual license tax of one hundred dollars ($100.00) for each such place of business the same to be collected in like manner as other licenses.

SECTION 4

An annual license tax is hereby imposed upon all airships kept or used for hire within the town, the same to be collected from the owner of such airship in like manner as other licenses. Said license tax shall be graded as follows:

Balloons—Stationary, twenty dollars ($20.00); Powerless, thirty dollars ($30.00); dirigible, fifty dollars ($50.00).

Flying machines—Aeroplanes, one hundred dollars ($100.00); heliocopters, one hundred and fifty dollars ($150.00); ornithopters, two hundred dollars ($200.00); all other types, three hundred dollars ($300.00).

Said amounts shall be increased according to carrying capacity, in the following rates:

Five to fifteen passengers, 10 percent increase; fifteen to thirty passengers, 20 percent increase; thirty to sixty, 35 percent increase; sixty to one hundred, 50 percent increase; one hundred to five hundred, 100 percent increase; five hundred to one thousand, 200 percent increase; over one thousand, 400 percent increase.

SECTION 5

For the purpose of encouraging transportation of freight by aerial common carriers, no tax whatever shall be imposed upon any common carrier for the term of 15 years from the date of this ordinance.

SECTION 6

No powerless balloon, aeroplane, helicopter, ornithopter or other type of flying machine or airship, shall travel upon any street or alley of the town within 10 feet of the surface at all, or within 20 feet of said surface at a speed greater than eight m.p.h.; or within 50 feet at a speed greater than 15 m.p.h.; or within 100 feet at a speed greater than 25 m.p.h.; or within 200 feet at a speed greater than 50 m.p.h.; or within 500 feet at a speed greater than 100 m.p.h.; or within one thousand feet at a speed greater than 200 m.p.h.

SECTION 7

It will be unlawful for the occupant or occupants of any balloon either stationary, powerless or dirigible, or aeroplane, helicopter, ornithopter or other type of flying machine or airship to drop, throw, discharge or otherwise eject any substance, fluid or solid from such airship, upon any of the streets, alleys or parks, or public or private lots, blocks or buildings within the town.

SECTION 8

It shall be unlawful for any such balloon or airship to collide with, break, destroy, deface or otherwise damage any electric, telephone, telegraph wires or poles or any part of any public building, or other property within the town.

SECTION 9

All such balloons or airships shall be properly equipped with, and shall use, such bells, whistles, or horns, brakes, lights and other signaling and controling apparatus, and net, parachutes, flying belts and artificial wings, and other safety apparatus as are prescribed by the rules and regulations adopted and enforced by the aeronautic bureaus of the United States government.

SECTION 10

As soon as practicable, the council shall purchase an aeroplane of approved modern type for the use of the marshal in performance of his public duties, and to enable him to properly enforce the provisions of this ordinance.

SECTION 11

Any violation of any of the provisions of this ordinance shall be punished upon conviction, with a fine of not more than $500 or by imprisonment in the town calaboose for not more than 90 days or by both such fine and imprisonment.

The brisk practicality of these rules is undoubted and the seeds of a great many future laws may be seen in these early efforts. For example, the rule about increasing altitude with speed seems likely to be repeated with supersonic aircraft. The second half of the nineteenth century saw a great deal of activity by writers on air law, culminating in the first International Aeronautical Congress at Paris in 1889—which appointed a Permanent International Aeronautical Commission to study certain legal questions. From this point onwards, aeronautical law came to be recognised as an international, rather than a national problem.

2.3. THE FIRST AVIATION LAWS FOR ENGLAND

England was not asleep and members of this Society at the turn of the century were playing a prominent part in shaping the future. If not the earliest, certainly the clearest exposition of future legal problems was made in 1909 by that great man Major B. Baden-Powell.[9] His prescience was remarkable. He stressed the necessity for what he called "Rules of the Road" to avoid aerial collisions and he realised that if international frontiers could not be recognised by aircraft, "Free Trade must result." He foresaw that "either Customs must be entirely done away with (except possibly as regards heavy and bulky goods . . . . .) or . . . . . all aerial vessels must descend at the Custom houses to declare their cargo." He realised the difficulties in prescribing private landowners rights in air space; and the need for identification markings on aircraft. In this latter connection he suggested the use of "four or five flags with the national ensign at one end" (painted on the aircraft and illuminated from within) as a more beautiful solution than "ugly numbers." For many years after he wrote (from 1919 in fact), flags were prescribed as one of the distress signals for use by aircraft. Not for another 35 years was one of Major Baden-Powell's most significant suggestions adopted—a new and *separate* government department for civil aviation.[10]

On the 19th November 1913, Mr. Roger Wallace K.C. was able to report[11] to this Society that national laws on aeronautics had been promulgated in France, Belgium, Holland and Germany. The time had come to consider further laws for England (i.e. *after* the Aerial Navigation Act 2nd June 1911).

It is hoped that this paper may be a limited contribution to the process of thought which he started:

> " . . . . we have to consider many theories governing a different kind of law and suggest means by which they can be reduced to practical regulations. We have not the same opportunities as the physicists, no official laboratories or opportunities for making experimental tests, and have to leave this to the cumbersome

9. *Law in the Air*, published in the National Review, March 1909 and reproduced here as Appendix B.
10. On 22nd October 1944 Lord Swinton became the first Minister of Civil Aviation.
11. On 19th November 1913 with Mr. Justice Atkin in the chair: reported in *The Aeronautical Journal* Vol. XVIII, January 1914, page 3. Paper entitled "The Right to Fly."

machinery of the administrative authorities of the governing political powers."

Mr. Wallace considered the vexed questions which were then current, *e.g.* the use of aircraft in war, the various theories about freedom in the air and proposals for an international convention on aerial navigation. Many of his views will bear extensive quotation and repetition today. With reference to proposed English legislation he said:

"Personally, I am not in favour of legislation at the present time, I think a great deal more study of the question and further experimenting with a view to safety of aircraft is required before the time is ripe for legislation."

Today we have some idea that there are no absolute or final standards in air safety. Mr. Wallace's caution in 1913 is worthy of emulation.

"The only laws that have been passed up to the present have been of a restrictive kind," he said, and he cited the example of legislation against motor cars which he thought had held up development for nearly 100 years. As a former chairman of the Royal Automobile Club he was severely critical of the new legislation which he thought simply encouraged "the idea that as long as you were going 20 miles an hour you could do no harm, and that the moment you went over it you became a general danger to the public, even when you were going along the roads with nobody in sight . . . . " Are we certain that we know better today on the road or in the air? Whatever part road speed limits play in reducing road casualties, it is still abundantly clear that, by itself, a speed limit does not prevent dangerous drivers from behaving dangerously even within the limits. Are there no lessons to be learned from this?

For example, do we know enough today about fatigue and sleep to formulate such complex rules[12] for the avoidance of flight crew fatigue? It is possible to legislate for minimum rest periods; but legislation can neither ensure rest nor sleep nor can it cope with the effects of East-West-East travel on digestive and sleep cycles, any more than road speed limits will cure dangerous drivers.

"Fortunately," remarked Mr. Wallace, "at present there is no law which forbids you to fly in general . . . . . " That situation has now changed drastically depending on what is the purpose and destination of the flight in question.

" . . . . the only good that the law can do would be to say that the airman has a right to be in the air with his machine provided he does no appreciable harm to anyone else—in other words, that the State should acquire by Statute the right to govern air traffic so that the aviator could fly not on sufferance but of right."[13]

It is most fortunate that the spirit of this very wise suggestion was adopted indirectly (albeit 7 years later) by the provisions of the Air Navigation Act 1920[14] which protected all ordinary aircraft operations from specific types of legal action provided that appropriate regulations were observed. This has been a widely admired feature of our law ever since. If only this simplicity could have been preserved in other directions.

Mr. Wallace was then Chairman of the International Commission on Air Law set up by the Federation Aeronautique Internationale and he submitted the text of a proposed international convention to regulate air traffic. It is interesting to isolate one single aspect for its present day relevance:

"In mist, fog, drizzle, snow or heavy rain, powered aircraft must, both by day and by night, emit intermittent loud noise-signals." Even with the low air speeds of 1913 this seems more like the repetition of a nautical tradition than the creation of an effective rule.

This Convention came to nothing, but by 1919 when the first International Convention for the Regulation of Aerial Navigation was signed in Paris[15] the relevant rule was "Rule 33—Every aircraft in a cloud, fog, mist or other conditions of bad visibility shall proceed with caution, having careful regard to the existing circumstances and conditions."

This was embodied into English Law by the Air Navigation Order 1922[16] (made under authority of the Air Navigation Act 1920), complete with a rule which was no doubt a comfort to the rule-makers but can have been of little practical help:

"Rule 34—In conforming with these rules, due regard shall be had to all dangers of navigation and collision and to any special circumstances which may render a departure from the above rules necessary in order to avoid immediate danger."

Referring to this Rule, which still persisted in 1927, Flight Lieutenant Cresswell Turner[17] said "I submit that no aeroplane travelling through cloud at 100 m.p.h. can 'proceed with caution.' If there is another aeroplane in that cloud, it is luck and luck alone which will prevent a collision under the existing regulations." He went on to propose rules which are the forerunner of the modern quadrantal rules.

From this distance in time it is easy to see the inadequacy of the rules even for their own time. Are our own rules better? So far as flights in controlled air space under Instrument Flight Rules[18] are concerned it is possible to be satisfied with the present level of achievement. But due to a shortage of staff, methods and equipment not *all* modern flights can be so controlled. A majority of collisions occur when the visibility is good. The wheel has turned a full circle. The modern problem is to avoid collision in clear air and the characteristics of ordinary human vision are not suitable for objects with a closing speed around 1,000 m.p.h. The eye with nothing to focus on at high altitudes in a blue sky does not easily see more than a few feet ahead of the aircraft

12. The Air Navigation Order 1960—Part V.
13. R. Wallace, op. cit. p. 16.
14. 10 and 11 Geo. 5 Ch.80 (23rd December 1920) Section 9(1). Now replaced by Section 40(1) of the Civil Aviation Act, 1949.
15. Treaty Series No. 2 (1922) Cmd. 1609—*See* relevant text for Note 28.
16. Although under the authority of the temporary Air Navigation Act, 1919 most of these Rules were already in force by means of the *Air Navigation Regulations* 1919 (when the Right Hon. W. S. Churchill was the relevant Minister).
17. *Journal Royal Aeronautical Society*, Vol. 31, 1927, pp. 411-419 "The Regulation of Air Traffic."
18. Section VI, The Rules of the Air and Air Traffic Control Regulations 1960.

whereas the Visual Flight Rules rely on the pilot being able to see five miles! Moreover it seems quite likely that a great deal more than 5 miles visibility is needed in order to give sufficient time for safe avoiding action by average pilots in these circumstances. We dare not laugh at the audible signals of 1913.

Of course it is really quite safe:

"An aircraft shall not be flown in such proximity to other aircraft as to create a danger of collision."

"Notwithstanding that the flight is being made with air traffic control clearance it shall remain the duty of the commander of an aircraft to take all possible measures to ensure that his aircraft does not collide with any other aircraft."[19]

2.4. THE PATH TO PARIS 1919

"It is somewhat remarkable that before any satisfactory progress was made in the development of aerial navigation many societies in various countries were formed for the consideration of the laws relating to aeronautics."[20] One reason was that since 1794 non-dirigible balloons were regularly used as an auxiliary of armies.[21] Lawyers seemed to be obsessed with the idea that by drawing up suitable rules, aerial vehicles could be outlawed for the purposes of war. This is not unlike the present situation in regard to a system of law for outer space.

When the first Hague Conference on the rules of war met in 1899, flying as we know it today was non-existent—nevertheless aerial bombardment was in the minds of delegates and was prohibited. In April 1909, Lord Montague of Beaulieu was ungentlemanly enough to suggest that future wars would be total wars in which every device would be used. With the approval of members of this Society he was taken to task by Col. F. G. Stone[22] who pointed out that war was a matter for experts and he declared there was "a conscious desire on the part of civilised nations to play their part honourably in *the great game of war*, in accordance with an ever progressive standard of humanity and moral obligation, which, so far as our experience goes, has hitherto been strictly observed." He recommended that no bombardment (including that from aerial vessels) "shall be permitted against place or locality, except for the purpose of destroying its defences or defenders, or the war material contained within its boundaries."

By 1911, one of the lawyers at the Madrid session of the Institute of International law was heard to say "I regret very much that the progress of science has made aviation possible."[23]

The big issue of the day was national sovereignty. There were many theories which are better discussed elsewhere[24]—but all hinged upon the extent of a state's right to control the whole of the air space above its territory. Largely for political reasons, a diplomatic conference in Paris in 1910 failed to agree on this issue, and then,

"during the years 1910 to 1914, national air laws were enacted by a large number of European States; they were without exception restrictive and based mainly on military considerations, for the First World War was already casting its shadow before."[25]

The first Aerial Navigation Act 1911 merely gave the Home Secretary power to prohibit flying over specified areas in order to protect the public. But with the passage of the Aerial Navigation Act 1913 and the resulting Home Office Regulations (1st March 1913) the skies of England were closed to foreigners without prior diplomatic permission. Adventurous, ignorant, alien aeronauts entered, were fined and complained[26] and Mr. Wallace reported that "we were placed," by other nations, "on a par with Roumania, who had forbidden any entry into the country. We were described as a retrograde and a savage nation."[27] We were accused of having started something—which was quickly followed by Russia, Italy, Austria, France and Germany. In a Franco-German agreement of 26th July 1913, military aircraft were forbidden to fly across the respective frontiers and civil aircraft could only enter with special clearances and permits.

The die was set and given full force and effect after the First World War in the 1919 Paris Convention[28] in which for the first time on a multilateral basis:

"The High Contracting Parties recognise that every Power has complete and exclusive sovereignty over the air space above its territory.

"For the purpose of the present Convention the territory of a State shall be understood as including the national territory, both that of the Mother Country and of the colonies, and the territorial waters adjacent thereto."

With suitable modifications this is the accepted situation today in all States which have ratified or adhered to the Chicago Convention on International Civil Aviation 1944. The U.S.S.R. (which is not a party to this Convention) defines its own sovereignty in similar terms. From this beginning, all states derive their rights to control international commerce by air.

Although it might look as though Great Britain took the first fatal steps, the result was virtually inevitable in time. Even if there had been a more liberal approach, it "would not have survived the First World War, and the resurgent economic nationalism which followed."[29]

Within this superstructure of sovereign air space, the peoples of all nations struggle to conduct air commerce.

"The extraordinary progress of the science of aeronautics during the last four decades is in strange contrast with the halting attempts to develop a public inter-

19. *Ibid.* Rule 17.
20. R. Wallace *loc. cit.* p. 3.
21. J. M. Spaight *Aircraft in War.* (Macmillan 1914).
22. A meeting on 8th November 1909, reported in Vol. XIV *The Aeronautical Journal*, January 1910.
23. J. M. Spaight *loc. cit.* p. 3
24. *The Law of the Air.* H. D. Hazeltine (University of London Press 1911).
25. R. Y. Jennings "International Civil Aviation and the Law," 22nd British Yearbook of International Law, 1945.
26. J. M. Spaight *op. cit.* p. 47.
27. R. Wallace *loc. cit.* p. 6.
28. Treaty Series No. 2 (1922) Cmd. 1609.
29. B. Cheng "The Right to Fly"—42 *Grotius Society Trans.* 195 p. 106.

national law of the air adequate for the regulation of this novel means of transport."[30]

History, in fact, is a nightmare from which no-one can awake.

3. Legal "Drag" as an Operational Parameter

3.1. SCHEDULED SERVICES

". . . . *complete and exclusive sovereignty over the air space* . . . . "[31] means that each nation is in strict control of every penetration of its air space for any reason whatsoever. In part 5 below it may be possible to gaze heavenwards and ask 'how high is up' for the vertical extent of air space. In this part, there will appear a brief review of problems in those portions of the lower atmosphere which are navigable by the air-breathing engines of commercial aircraft—a horizontal exercise.

Without exception *scheduled* air services between one state and another may only be operated in accordance with the terms of specific agreement with the governments concerned.[32] These agreements usually provide for the operation of such services solely by carriers designated by the respective governments at fares and charges to be approved by the governments. This has given rise to something like 500 bilateral agreements "which judging by the experience of the past, is bound to retard the development of an efficient system of international civil air transport."[33] "There can be little doubt that air transport diplomacy was responsible for delaying, perhaps for several years, the establishment of regular air services on the last great international route—the northern transatlantic."[34] Today, the Pacific and trans-Polar routes are increasing in importance.

The privileges exchanged in these *bilateral* agreements are usually the ironically-named 'Five Freedoms':[35]

1. Transit *without* landing.
2. Transit with landing but *without* picking up or setting down traffic.
3. Putting *down* traffic which is taken on in the aircraft's State of Registry.
4. Picking *up* traffic destined for the aircraft's State of Registry.
5. Picking up *and* setting down traffic destined for *or* coming from any third State (which need not have any contractual agreement with either of the two bargaining States).[36]

Discussions between States on the 'Fifth Freedom' involve each State in fantastic arguments about each other's airline operations into, and out of, countries which are not parties to the discussions! Future generations may well judge the mere definition of the five freedoms as the most serious obstacle to the growth of international air transport in the post-war era. There is no doubt that the notion of the five (or eight!) freedoms is invaluable in political or economic bargaining. In Europe, where a dozen nations jostle side by side, and national frontiers may be crossed several times each hour by air, the passage of time is eroding the practical value of these theoretical concepts. It has already been suggested that States should simply agree upon terminal points in each other's territory for the use of scheduled services and that if governments *do* wish to argue about the amount of traffic flowing between their capitals then they *can* do so in a way which will not hinder the economic growth of Air Transport.[37]

The pattern of bilateral agreements is now so complex and deeply embedded in international politics that any idea of a revolutionary change is out of the question. But if two governments such as the U.S.A. and the U.K. can approach the idea of abandoning route agreements—there is every prospect that the rest of the free world would follow suit. Practical scientists and practical business-men alike need have no hesitation in challenging their governments at every opportunity to justify the persistence of these outmoded theoretical concepts into the second half of the first century of aviation. The purpose they served was to inject cautious stability into post-war expansion. The future requirements of inter-governmental agreement will be to permit round-the-world operations of internationally-owned and internationally-operated supersonic aircraft on a variety of routes.

A first step towards this will be the ceremonial burning of the tattered "freedoms of the air."

3.2. NON-SCHEDULED SERVICES

If anything, the restrictions on non-scheduled services are even worse.

"If Cobden and those who preached Free Trade amongst nations had possessed any idea of the possibilities of the conquest of the air and its consequences, they would have had stronger arguments as to its future necessity" wrote our mentor of 1913.[38]

The Chicago Convention of 1944 gives nothing away. Even non-scheduled non-traffic transits through a State may be the subject of "special permission"—ostensibly on the grounds of safety. If non-scheduled carriers propose to take on or discharge passengers, cargo or mail then each State may "impose such regulations, conditions or limitations as it may consider desirable."[39]

In an age where 500 m.p.h. aircraft are available to the world of commerce "it is sometimes necessary to apply for clearance with notice varying from three to ten days, in some cases up to sixty days, prior to the intended date of the proposed flight."[40] Europe has always been

30. R. Y. Jennings *loc. cit.*
31. Article 1 of the 1944 Convention on International Civil Aviation I.C.A.O. Doc. 7300/2 (Original signed 7th December 1944).
32. Art. 6 Ibid., and by custom and special agreement with States not parties to the Chicago Convention.
33. R. Y. Jennings, *loc. cit.* p. 15.
34. Lissitzyn *International Air Transport and National Policy*. (1942) p. 402.
35. Dr. Cheng distinguishes EIGHT freedoms (including Cabotage)! *loc. cit.* p. 111.
36. The International Air Transport Agreement 1944.
37. "Open Skies for Air Transport: What is the price of Traffic Rights?" by T. B. Hurld, p. 874 *Flight* 1960 (24th June). The suggestions in this article would make it unnecessary to distinguish between scheduled and non-scheduled air services.
38. R. Wallace *loc. cit.* p. 7.
39. Article 5.
40. "Freedom of the Air" Airbrokers' Association (London).

the home of international aviation co-operation and therefore it may be regarded as a major achievement that so far 16 European nations have signed a "Multilateral Agreement on Commercial Rights of Non-Scheduled Air Services in Europe"[41] in which, in addition to the limited classes of service which will be admitted WITHOUT "regulations, conditions or limitations," other non-scheduled flights will be subject to a MAXIMUM period of prior permission of not more than "two full business days" for single flights or a series of not more than four flights. Even this multilateral concession seems to be strangled by time-consuming delays.

M. Desouches, at the 1912 Paris Conference of the International Law Association would surely win the approval of the Airbrokers' Association without relying on the fact that his paper bears the same title "La liberte de l'Air' as their pamphlet in 1960:[40]

"It is not presumptuous," he said,[42] if we regard the very size of the aerial ocean around us as giving "to all those who are engaged in aerial navigation an independence which effectively permits them to easily withdraw themselves from the application of all theoretical regulations meant to restrain their right to the free use of the air." He contended "that aeronauts know best how to choose their own route . . . . " and he further affirms "that it is practically impossible to prevent aeronauts crossing boundaries . . . . it would be impossible to oblige them to descend at the frontier or other specified places . . . . (and) modern thought would not allow of enforcement of any Draconian punishment on the descent of the aeronaut infringing regulations, ... " "The usual geographical frontiers have no meaning as far as aeronauts are concerned, therefore, in times of peace the State should have no jurisdiction over an aeroplane until the moment of its landing . . . . "

Among the examples cited by the Airbrokers' Association, two may be noted:

(*i*) An aircraft was chartered to carry a ship's crew from Bombay to the United Kingdom—subject to clearance by the Indian authorities—who would only give permission if the Indian National Carrier gave a "no objection" certificate. This was not forthcoming because there were seats available on Air India International. The result was that the ship's crew travelled by *other* scheduled services. The charter operator AND Air India both lost the business.

(*ii*) In order to deliver a cargo of television sets to Baghdad, application had to be made via diplomatic channels and translated into Arabic before the Iraqi authorities would consider the application. The overall effect was that 9-10 days notice was required which could not be fitted in with the short notice upon which charter space became available.

The usual reaction of an aeronautical scientist or engineer on hearing about irritations of this nature is "what has all this to do with me?" The answer is to be found in the technical and economic inter-dependence o air commerce, aircraft manufacture and aviation researc and development. The Defence White Paper of 195 showed the folly of reliance exclusively on an avuncula State to peer god-like into the future, pay all foreseeabl bills and provide a never-ending programme of researc and development for purposes as mysterious as those o the universe. Mach 3 air liners which demand a planne utilisation throughout every hour of the year for thei economic viability will be useless if the commercia operators of fifteen years hence have to wait ten days fo diplomatic clearance. Planning for the future cannot b confined to hypersonic wind tunnels and sophisticate materials if there are no ultimate customers. The la applicable to international air services is NOT just matter for government experts: it is they who have bee the architects of the *status quo*. This is the danger of a age of specialisation. Members of this Society have solemn duty to consider that all aspects of air commerc are of as great an importance to them as, say, th National Health Service—with the added advantage tha they can claim to know something of the subject. Britis aeronauts may even wonder why the conditions whic they will have to satisfy before indulging in a commerce[43] should be so much more stringent tha those applicable to foreign air carriers operating into th U.K. For example, the shortest period of notice require for a licence application for a charter service "involvin not more than three flights in each direction between th same two places" is 72 hours. Certain other charte licence applications require from 14 days to 3 month notice depending upon which part of the world i involved. If the rules are justified as being absolutel essential for U.K.-registered operators, are they no equally desirable for all aerial vehicles which are likel to terrify the population or compete with the Ai Corporations?

Law is but the formalisation of a society's minimum needs in terms of rules of conduct. Some deficiencies in the current rules for air operators have been noted above and aeronautical scientists must find ways of exerting their influence in rational directions for change. As Karl Marx might have said, "Scientists of the world unite—you have nothing to lose but your dreams!"

But of course, none of these problems can be solved in isolation, without consideration of the international hot or cold war. " . . . . States cherish the power of encouraging the development of air lines designed to strengthen political ties and potential military alliances. There seems to be little hope of removing this obstacle to a comprehensive system of public air law short of devising a satisfactory system of international security. but this is a larger problem."[44]

3.3. SUPERSONIC AIRCRAFT

It is generally recognised that each nation today has its own airlines largely for reasons of "diplomatic

41. Treaty series No. 42 (1960) Cmnd. 1099. The U.K. adhered to this Convention on 11th January 1960.
42. In a translation by R. Wallace, *loc. cit.* p. 9.
43. As a result of the Civil Aviation (Licensing) Act 1960 and the ensuing Civil Aviation (Licensing) Regulations 1960.
44. R. Y. Jennings, *op. cit.* p. 19.

prestige, national pride and strategic position."[45] If the Mach 2 or 3 air liner is pressed into airline service then the size of the anticipated capital investment is such that only a very few routes, such as the North Atlantic, are likely to be operated by single airlines owning their own supersonic craft. Elsewhere—for example in Europe—there is every likelihood that supersonic aircraft will be jointly owned and operated by several airlines of different nationalities. The Scandinavian Airlines System and their link with Swissair, Air Union and other linkages are likely to prove even more popular in the future, not only as a means of providing capital, but more important still—the pooling of traffic rights (as distinct from the pooling of operating revenue,—which merely reduces competition).

Aircraft may only be validly registered in *one* State, and each State generally requires that registration be confined to the legal or beneficial interests of its own nationals or firms registered for business purposes in their territory. Governments of the future will *have* to make allowance for a sharp separation between legal ownership, beneficial ownership, rights of possession and use—and all on *international* bases rather than national bases. The U.K. is already prepared to register aircraft if they are merely chartered to (rather than owned by) qualified persons.[46] Even greater concessions may be necessary over the next twenty years.

One of the most significant legal and practical consequences of cruising at Mach 2 or 3 will be the shock waves generated by the aircraft: " . . . a 180-ton Mach 2 or 3 air liner flying at 70,000 ft. . . would sweep the earth's surface with a thunderlike noise along the entire supersonic flight path, the effect being rattling and often shattering of windows and awakening sleeping people within a band of disturbance of some 70 miles width."[47] It is not yet clear whether there will be a close correlation between the altitude necessary to reduce ground pressure waves to acceptable levels and the altitude necessary for reasons of operational economy. If these altitudes turn out to be very different from each other, then the other alternative will be route deviations—again unattractive economically. Nor is it certain how close to conventional airways and subsonic aircraft it will be safe to allow supersonic operations.

In the United Kingdom there is little doubt that the registered owner of a supersonic aircraft would be absolutely liable for damage done by the shock waves irrespective of negligence.[48] But the minimum height for such aircraft is not likely to be much less than 50,000 ft. How can they possibly be identified at such heights? Small errors in altitude or routing can create havoc in terms of nuisance—even if not in terms of physical damage. If it proves impossible to identify the culprits as a matter of course then action will be needed to deal justly with the suffering of innocent ear-shattered citizens. Supersonic aircraft operators may perhaps be asked to contribute to a joint fund for the study of these problems and the provision of compensation for those who may be uninsured for such losses.

It may be too early to decide whether the contributors should be governments or airlines or both. The only thing certain is that solutions must be found within the foreseeable future otherwise public opinion alone may act as a powerful inhibiting influence on the use of supersonic monsters. I.C.A.O. has scarcely got this task on its worksheet. Those who may underestimate the extent of public irritation with noise, or the power of organised opinion (such as ratepayers' associations) may be reminded that the public fears after a series of crashes in the New York area succeeded in closing an airport. In this country, fear of public reaction caused the cancellation of tests designed to provide information on the size, nature and possible nuisance of sonic bangs!

In 1913 Mr. Justice Atkin said "If the aeronaut caused any damage or annoyance, as for instance, by letting substances fall from the air-vessel, or possibly by seriously alarming flocks or herds, he would be rightly held liable. In the absence of any damage or annoyance he would for all practical purposes be free from liability either by way of damages or injunction."[49]

With the exception of the remarks on "annoyance," that is still the situation today:—

"No action shall lie in respect of trespass or in respect of nuisance, by reason only of the flight of an aircraft over any property at a height above the ground, which, having regard to the wind, weather and all the circumstances of the case is reasonable, or the ordinary incidents of such flight so long as the provisions of . . . . (The Air Navigation Order 1960 and any rules made thereunder) . . . . are complied with."[50]

These seem clear rules for supersonic aircraft to obey.

Further protection is given to aircraft which are on certain aerodromes (mainly of a non-private nature) and that make noise and vibration during such normal operations as take-off and landing and running-up engines. Such aircraft are protected from actions for nuisance.[51] Those who operate from purely private aerodromes, or make an infernal noise in other places[52] may in suitable circumstances, be subject to ordinary actions for nuisance at the suit of aggrieved citizens—just as in 1919 the residents of Chiswick, Hammersmith and Barnes were successful in restraining the testing of aero-engines at a factory.[53]

45. Report of the Aviation Securities Committee of the Investment Bankers Assocn. of America. (Submitted to the I.B.A. Convention December 1960), p. 16.
46. Art. 2(5) of the Air Navigation Order 1960.
47. Bo Lundberg in a talk entitled "Should Civil Supersonic Aviation be permitted?" given at the Flight Safety Foundation International Air Safety Seminar, November 1960, Arizona. *See also Journal of the Royal Aeronautical Society*, February 1961.
48. Section 40(2) of the Civil Aviation Act 1949; and see "The Sound Barrier: Aircraft Noise and Insurers", *J. of the Chartered Insurance Institute*, Vol. 53. pp. 13-34, 1956.
49. XVIII *The Aeronautical Journal*, p. 30.
50. Section 40(1), Civil Aviation Act 1949.
51. Section 41 Ibid. and Regulation 10 of The Air Navigation (General) Regulations 1960.
52. *See*, for example, paper by A. R. Paterson calling attention to the serious situation in the U.S.A. and Canada: "When is an Aircraft a 'Nuisance' in the eyes of the Law?" I.A.S. Preprint No. 756.
53. *Bosworth-Smith and Others v. Gwynnes Ltd.* (1920), 89 L.J. Ch. 368.

Our pre-war guide, Mr. Wallace, could ingenuously assert "I do not say that the passage of Hertzian waves through the atmosphere does any harm, but certainly the passage of an aeroplane through the atmosphere equally does no harm."(54) Fortunately no system of law was built on these propositions.

If it were not for international agreements (such as those reached under the banner of the International Telecommunications Union) concerning the use of radio frequencies, the "Hertzian waves" would do a great deal of harm simply by multiple broadcast interference. Even more serious are the high-energy microwave transmissions associated with certain radar installations. They can be harmful to life. There is also the problem of cosmic radiation: "we have to be absolutely certain, before we enter into supersonic adventure, that harmful biological—in particular genetic—effects due to cosmic radiation at the 'supersonic' altitudes are non-existent"(55).

The passage of a supersonic "aeroplane through the atmosphere" will do a great deal of harm unless it is flying high enough. By its combination of potentially harmful elements, the supersonic aircraft will be lucky if it survives without acquiring the legal classification of something inherently dangerous; it will have:—

(*a*) Unsurpassed potential, kinetic and explosive (pressure-cabin) energy.
(*b*) Heated fuel within striking distance of hot wings, and red-hot engines.
(*c*) High-energy microwave equipment.
(*d*) Thundering shock waves and a high general noise-level.
(*e*) An environment whose biological safety has yet to be proved.

It will be a challenge both to science and the law to ensure that these intrinsic factors can be harmlessly controlled and transformed into an acceptable instrument of commerce without giving rise to unwelcome legal liabilities.

Society as a whole is still jealous of national sovereignty and of the liberties of its citizens and unless these problems are met squarely there is a grave risk that legal limitations on "the right to fly," on international ownership and control, and on liabilities in general (both for damages and for taxes)(56) may constitute a serious inhibiting operational parameter which the aeronautical scientist can only ignore at the peril of his livelihood.

3.4. DOCUMENTATION

So long as paper and the printed or written word remain as a cheap method of recording and transmitting information, paper is likely to remain as part of the essential debris of our struggling civilisation. Aircraft operations seem to be swept by a continual paper blizzard.

A design is started on paper, construction contrac are created on paper, punched tape can control fabr cation, inspection records are interred solemnly in pape graves and so it goes on—testing, flight-planning maintenance, licensing, instruction, sales, custom consignments, tickets, inventories, administration an even papers to the Royal Aeronautical Society ar impossible without gallons of ink and miles of paper.

As the technology of information storage an retrieval advances it is to be hoped that some way can b found to stem this massed dissemination of pulped tre throughout the world. Not simply for the sake o preserving natural forests—but to break the tyranny o the WRITTEN or PRINTED record.

The sanctity of a written contract, or quadruplica customs forms cannot be disturbed until better means ar found for recording the same information. It is par cularly heartening therefore to see the concerted resis ance by operators to the introduction of further forms fo passengers to fill up—ostensibly for statistical pu poses.(57)

Customs *rules* of course are the natural consequenc of national trade barriers in the form of tariffs. Unt the tariffs disappear there can be little progress in th direction. What aircraft operators would like is a clos co-ordination of customs procedures to match the roun the-clock 500 m.p.h. capability of modern aircraft.

Although airlines need certain minimum records fo inter-airline accounting purposes, one of the bigge obstacles to any simplification of passenger docume tation is undoubtedly the 1929 Warsaw Convention(58) which was a remarkable achievement for 1929 but is terrible nuisance (so far as documentation is concerne today. There must be a ticket delivered in respect of eac passenger, and the number and weight of pieces o baggage must be entered thereon.

The Warsaw Convention insisted on the issue o tickets and the incorporation of standard condition therein because old-fashioned legal rules say that in th CIVIL law, conditions on a ticket are only effective they are brought to the attention of the passenger.(5 This is ridiculous because there are many other ways o bringing conditions to a passenger's attention, *e.g.* b filing standard conditions in a public record (as is don in the U.S.A.). The rules also depend upon the practica fiction that a passenger has the inclination, stamina o high-power lenses sufficient to read the ticket condition The *criminal* law on the other hand works on th assumption th[illegible] citizen is capable of knowin (let alone adhering to) [illegible] rule in the book.

In this country, an enlightened government ha scrapped such documentation requirements for carriag by air which is outside the scope of the Warsaw Con vention.(60) This is a fairly clear indication that suc requirements could be abandoned even for 'Warsa

54. *loc cit.* p. 14.
55. Bo Lundberg, *op cit.*
56. The 1944 Chicago Convention is silent on the question of State's rights to TAX transient aircraft. There are uncomfortable indications—particularly in the U.S.A.—that the tax laws of the pioneering Mayor of Kissimee City may be reborn elsewhere to harrass air commerce.
57. *The Times*—24th October 1960. It is now understood th other methods of data collection are being explored.
58. Embodied into English law by the *Carriage by Air Act* 1932.
59. For example *see Fosbroke-Hobbes v. Airwork Ltd. and Britis American Air Services Ltd.* (1937) All E.R. 108.
60. The Carriage by Air (Non-International Carriage) (U.K. Order 1952.

Carriage' (if the definition of such carriage could be extended)—but the opportunity was NOT taken, when amendments to the Convention were last drawn up in the Hague in 1955. The Hague Protocol (if it ever receives sufficient ratifications to become effective) will eliminate any drastic results if the baggage weight particulars are omitted from the ticket—but it leaves undisturbed the principle that baggage liability limits are geared to the *weight* of registered baggage. Therefore for the whole of the foreseeable future it seems likely that international air carriers will have to go through the useless process of entering the total number and weight of a passenger's bags onto his ticket. With aircraft loads well over 100 passengers—each with two or three pieces of baggage —the time consumed by this process can easily be imagined. In practice, the air carrier only needs to know how much *excess* baggage is being carried per passenger, together with the *total* amount of baggage per aircraft, or per baggage hold compartment. (It seems curious that there has been little technical progress in the automatic weighing of passengers and their baggage as they arrive at check-in-points—suggested to this Society in 1913[61].)

In the Convention there are single limits of carrier's liability:

(*a*) For injury, death or delay or delay to a passenger (125,000 Gold Francs)[62]

(*b*) For objects of which the passenger takes charge himself (5,000 Gold Francs).

There seems no good reason why there could not be a similar limit—say 10,000 Francs for registered baggage—subject to proof of damages in each case. This would open the way to simplifications in documentation consistent with the coming century of air transport.

4. Scientific Causation versus Legal Liability

4.1. THE SHIFTING BURDEN OF PROOF

Even for a scientist or a philosopher "truth" may be no more than the best-known approximation to something which may forever be just outside reach or comprehension. "Truth" in determining the causes of accidents depends on the application of scientific method to the available evidence which is often fragmentary. Sometimes it is possible to reach a fairly certain answer. Sometimes this is impossible. In a public inquiry—conducted on, say, the English or American model—scientific truth may be weighed in an informal, but judicial, manner. Science and the law can combine very effectively in a search for objectivity. In an imperfect world, the findings of such inquiries held by competent men probably represent the best approximation to the "truth" of accident causes.

But the legal liabilities arising out of such accidents, even though they may be based on the same facts, need have only a tenuous superficial connection with the apparent causes, scientifically determined. This is not a true conflict. It is a creation out of a separate world: the world of civil obligations in which are described the nature and extent of one man's legal responsibilities to another.

In English law, legal liability is based on the concept of a legal duty. The legal duty may arise out of a contract (such as a contract for carriage by air) or it may arise by implication of law. For example, it is a "great principle of social duty that every man in the management of his own affairs whether by himself or by his agents or servants shall so conduct them as not to injure another; and if he does not, and another thereby sustained damage, he shall answer for it."[63] From this basis has been developed the legal doctrine whereby a person such as an aircraft manufacturer may be liable to any person who is injured by that aircraft IF the injury is caused by some defect in the aircraft which the manufacturer alone had the opportunity to prevent (having regard to the state of knowledge in the industry at that time).

But the evidence developed by a scientific inquiry cannot be accepted without proper legal scrutiny in open Court. Thus the basic evidence has to be weighed, sometimes by a judge acting alone, sometimes by a judge with the aid of a jury (whose job in England in such cases is to make findings of fact). This can have curious results. Following an accident in Canada two courts reached different results using virtually the same facts!

At an altitude of 75 feet after take-off, the propeller blade of a single-engined aircraft snapped and caused the aircraft to crash. Investigation revealed an old fatigue crack in the hub shank and the case turned upon whether the air carrier ought to have detected the cracked shank before take-off. In the first case to come before the courts the judge felt that the accident was really caused by faulty design and he exonerated the *carrier* from any legal blame.[64] In later trials of two other actions against the carrier, it was said that further evidence was available, but really the judge based his decision on the precautions which should have been taken by the carrier as a result of an Information Circular from the Canadian National Defense Department which gave guidance on the overhaul of propellers. The same circular had been discussed by the first judge. Nevertheless in the second group of cases, the judge found that the carrier had been negligent and awarded accordingly.[65]

Even though there may be reasonable doubt about the objective scientific cause of an accident, the legal liabilities need not be similarly indeterminate. The law will be settled at the trial of the action and will depend upon the person who has to discharge the legal burden of proof. Under the common law, a passenger injured in an aircraft accident would have to prove that the air carrier was legally negligent, *i.e.* that the air carrier had departed from the standard of care which the law expects. In such circumstances the burden of proof is said to be on the plaintiff (who is injured) and this may often be a difficult and expensive task because the reports of official investigators cannot simply be handed in as evidence. It is necessary for the plaintiff to get such

61. By Capt. C. M. Waterlow: *The Aeronautical Journal*, Vol. XVIII, p. 37. "The Coming Airship".
62. Just under £3,000 at present gold prices.
63. *Farwell v. Boston and Worcester Rail Road Corp.* (1842) 4 Metcalf 49.
64. *Galer v. Wings Ltd.* (1939) 1 DLR 13.
65. *Nysted v. Wings Ltd.; Anson v. Wings Ltd.* (1942) 3 DLR 336.

witnesses as he can and persuade them to explain the accident in such a way as will demonstrate the defendant's negligence.

But if "the accident is such as in the ordinary course of things does not happen if those who have the management use the proper care, it affords reasonable evidence, in the absence of explanation by the defendant, that the accident arose from want of care."[66] It is said, in effect, that the facts speak for themselves (*res ipsa loquitur*) and the result is to shift the burden of proof. It is then for the defendant to prove himself "innocent" of the charge of negligence. (Quite the reverse of the *criminal* law where, in England, the accused is innocent unless proved guilty.)

In 1937 Mr. Justice Goddard (as he then was) had no hesitation in applying this doctrine to an accident in which an aircraft crashed immediately after take-off after gaining 75 to 100 feet in height.[67] The pilot thought he had hit a downdraught caused by a ploughed field but the judge preferred the evidence of other witnesses who had said in effect "that the pilot started his run and left the ground with the tail-end of the machine too far down, at an angle which prevented the machine from gaining speed, and caused it to stall.[68] It is unnecessary to decide the precise reason why he allowed the machine to be at this angle." So after holding that *res ipsa loquitur* was applicable, the judge found that the defendant had failed to discharge the burden of proof upon him and had failed to provide a satisfactory explanation of the cause of the accident (supported by evidence) which did NOT involve his negligence. So, for example, where an airline could not explain an accident, but only suggest possible causes, this doctrine of evidence operated to make the carrier liable.[69] In cases where the 1929 Warsaw Convention[70] is applicable, the air carrier is liable UNLESS he can use certain specified defences.

4.2. PROTECTION BY CONTRACT

The application of these legal rules to cases involving manufacturing defects will always put the manufacturer into the position of trying to prove that the defect which caused the damage or injury did not arise due to any want of care on the part of the manufacturer. The English cases start with an historic decision of 1932[71] and the American cases are derived from a landmark case in 1916.[72] The persons entitled to sue in cases of this nature will include members of the public who may be injured by an aircraft which crashes as a result of a manufacturing or a design defect, and also, passengers on board. The only protection which a manufacturer can seek is:

(*a*) By ensuring high standards of design and quality control.

(*b*) By effecting suitable insurances.

If, however, the manufacturer is related by CONTRACT, *e.g.* to a sub-contractor, or to a purchaser of his aircraft, then, because English law recognises what is called 'freedom of contract,' the manufacturer can modify his legal liabilities *towards the contracting parties only*. This is cheaper than insurance and, if the contract terms are upheld by the courts, they may effectively prevent an airline from recovering the expenses which they have suffered as a result of the faulty aircraft which was sold to them. Since each aircraft is a complex assembly of components often made by hundreds of different sub-contractors, usually some attempt is made to impose suitable contract terms as between prime contractor and suppliers. This is the area where the 'freedom of contract' can turn into insane exchanges of worthless pieces of paper—because the exchanges may be evidence that the parties failed to reach clear agreement on their contract terms.

Each contracting party who discerns the liberty allowed to him by our law of contract will try and impose contract terms which are as favourable as possible to himself. For example, he will try and restrict his liabilities to the replacement or repair of parts which he considers faulty—even though the failure of the part can wreck a whole aircraft and kill scores of people. In fact it is a fear of these consequences which inspires "exemptionitis"[73] in the manufacturing industry and among the airlines.

The 'freedom of contract' becomes wholly illusory. It becomes a mere exercise in bargaining power. The party in the strongest bargaining position will win.

What is the result when legal rights of recovery are barred by contract? The simple result is that the party who would otherwise be legally liable is able to hide behind his contract terms and escape without either adverse publicity or personal cost.

It does not matter whether the losses are covered by insurance. The use of exculpatory contract terms will shift the financial loss to a blameless party and can rarely be excused on the grounds of negotiating parity. This will ultimately result in increased premiums for those sections of the industry which are represented by the blameless party—even if it does not result in severe direct financial loss. The liabilities arising out of aircraft accidents are rising in value each year. This should inspire a return to common law negligence as the guide to the liability of each party. There are a few pioneers[74] in this direction whose efforts are to be applauded.

The rest—including Governments (the worst offenders!), major airlines and major aircraft manufacturers—are riddled with exemptionitis. In the long run it cannot be satisfactory for portions of society to bear burdens for which they are factually and morally blameless. The industry should rely upon its scientific and technical skill and not upon legal adroitness.

It may even be necessary one day to consider a law which would make it impossible for any party to a

66. *Per Erle C. J. in Scott v. London and St. Katherine Docks Co.* (1865) 3 H. & C. at p. 601.
67. *Fosbroke-Hobbes v. Airwork Ltd. and British American Air Services Ltd.* (1937) 1 All ER 108-114.
68. Reminiscent of certain Comet accidents, nearly 20 years later!
69. *Malone v. T.C.A.*; *Moss v. T.C.A.* (1942) 3 DLR 369.
70. Embodied into English law by the *Carriage by Air Act* 1932.
71. *McAlister (or Donoghue) v. Stevenson.* (1932) AC562.
72. *Macpherson v. Buick Motor Co.* (1916) 217 N.W. 382.
73. A gross inflammation of exemption clauses.
74. *e.g.* B.E.A. in current Handling Agreements with other airlines. The French legal system has a more enlightened attitude to this problem.

contract (including the Crown) to exclude liability for negligence—but there should be nothing to prevent the parties reaching agreement on methods of *limiting* the amount of liability to sums representing a genuine pre-estimate of damages. Our law will already prevent the parties from taking advantage of figures which are too high for this purpose—on the ground that they are *not* genuine pre-estimates of damages and thus constitute unenforceable penalties.

If it became unlawful to exclude liability for negligence by contract, then the courts might need an additional safeguard—to strike out a clause *limiting* liability if it appeared to be unreasonably low.

4.3. AIR CARRIER'S LIABILITY

The liability of international air carriers is largely regulated by the pioneering Warsaw Convention of 1929—the object of which was to unify, so far as possible, the rules of legal liability relating to air carriers. Several countries (including the U.K.)[75] have applied similar rules to carriage not otherwise governed by the Convention. The principal effect of the Convention is to place the burden of proof on the carrier to show that he was not at fault. In return for this simplification, the liability of the carrier is limited UNLESS he fails to deliver certain documents of carriage correctly or UNLESS he is guilty of wilful misconduct.[76] None of these matters can be varied by terms in the contract of carriage.

Apart from a few countries in the Middle East and in Central and South America, the Convention has been widely accepted. Except in the U.S.A.[77] it appears to be quite successful in its broad intentions. Although the limits of liability in the Convention were geared to the price of gold, they have since been thought to be low (present value around £3,000 in respect of injury, death or delay to the passenger) and in 1955[78] the text of an amendment to double this limit and effect other changes of a less sensational nature was agreed. The U.S.A. is considering ratification of the amendment and a minority in that country wish to denounce the whole Convention.[79] A similar opportunity will soon present itself in the U.K.: on 21st April 1961, a private member's Bill passed its first reading in the Commons with the object, among other things, of ratifying the 1955 amendment.

Is it worth preserving the broad scheme of liability presented by the Convention? In the interests of international uniformity the answer must be yes. But in many areas the Convention has failed to achieve the desired uniformity. For example, the carrier's legal liability to passengers on one and the same aircraft may be governed by the Convention for some passengers but not necessarily for all of them!

Were it not for the existence of unpredictably high awards of damages in American courts whenever the Convention or its limits are inapplicable, then there might be a good case for suggesting that the *limitations* of liability could be removed in the interests of the travelling public.[80] Although the risks of air travel are indeed commonplace, the fact that an air traveller can always insure his life ought to be irrelevant. Therefore there seem to be reasonable grounds for saying that wherever the general public is concerned, there should be no restriction on rights of recovery whether by Statute or by contract. Different considerations apply to the relationships between commercial undertakings.

4.4. GENERAL CONCLUSIONS

The concept of scientific causation of events arises from a logical synthesis of known facts and may, if sufficient facts are known, lead to an accurate description of all the factors involved in, for example, an aircraft accident. This can give rise to a chain of 'technical responsibility' involved in the accident causation.

Legal liability for the consequences of such accidents—in terms of the destruction of life and property—is dependent entirely upon the operation of legal rules. Some of the legal rules are derived from international conventions, some are derived from rules of evidence in the common law, some are considerably modified by statute and in certain circumstances legal liability may be halted by the erection of contractual barriers. Therefore, although based on the same initial facts, the operation of rules of legal liability can produce an ultimate legal or financial responsibility which is very different or even in contradiction to the 'technical responsibility' derived from concepts of scientific causation.

Ordinary ideas of what is 'just' or 'reasonable' are increasingly being based on a wider appreciation of scientific causation. This is therefore another area in which it seems necessary for the law and science to collaborate in bringing ideas of legal liability closer to those based on scientific causation.

5. Out in Space

5.1. GENERAL NATURE OF INTERNATIONAL LAW

International law is a description of the nature and operation of common consent between sovereign nations. Perhaps as Jenks says,[81] it is "the common law of mankind in an early stage of its development." In the work of describing and analysing the structure of international law, jurists work logically using a "scientific method" very much in the same way as scientists or engineers would do. But there the resemblance to the work of science stops.

75. The Carriage by Air (Non-International Carriage) (U.K.) Order 1952.
76. *See Horabin v. B.O.A.C.* (1952). All ER 1016 for a definition of "wilful misconduct."
77. *See* (*a*) *Komlos v. Compagnie Nationale Air France* 111 F. Supp. 393; 75 S.Ct 31.
(*b*) *Noel v. Linea Aeropostal Venezolana* 24 7 F 2d 667; 78 S.Ct 334.
(*c*) "The Cause of Action under the Warsaw Convention" by G. N. Calkins Jr., *Journal of Air Law and Commerce* (Summer and Autumn 1959).
78. Hague Protocol. Cmd. 9824.
79. *See* 26 *JALC* 3, 267.
80. This would be consistent with the view of our Courts. See *Nunan v. Southern Railway Co.* (1923) 2KB703.
81. The Common Law of Mankind, by C. W. Jenks. p. 14. Stevens, 1958.

For when jurists attempt to predict the future practice of international law they are continually apt to be frustrated by the waywardness of the sovereign nations which they study. The fault lies not in the legal method but in the freedom of action which is possible to a sovereign power. Despite the immense moral force of United Nations there is still no World Policeman who can arrest a delinquent nation and bring it to trial before a World Court capable of rendering and *executing* appropriate judgment. If private individuals behaved towards each other in the same selfish way as nations do, then most people might find themselves in prison. The behaviour of nation to nation too often resembles a distillation of human self-interest, greed and stubbornness—rather than a distillation of human good and wisdom.

In areas where there is as yet no discernible structure of law—for example, in the voids of interstellar space—every man on earth may be entitled to say what he would like the rules to be. "One of the difficulties of the matter is, of course, that in general, international lawyers have little or no knowledge of or interest in astronomy, and astronomics, astrophysicists and rocket engineers little or no knowledge of, interest in, or perhaps even belief in, international law."[82] The opinions of eminent jurists undoubtedly influence the official policy of the sovereign nations and hence for some years writers have been discussing real and imaginary problems in the law of space.

5.2. REAL AND IMAGINARY SPACE GAMES

To professional soldiers, the notion that war is a "great game"[83] or a sacred duty dies hard. From the beginning, the possibilities of aerial warfare have shaped the foundations of international air law, and men of peace (including lawyers) have fervently addressed themselves to the task of consecrating air space and outer space for peaceful purposes. There is a superstition that if everyone talks about the peaceful use of space often enough and long enough, this will ensure that space will rejoice in peace.

Because the 1944 Chicago Convention and the U.S.S.R. define sovereignty in terms of "air space," argument rages over how high this extends. Lawyers argue that they need only discover the physical extent of the atmosphere to discover the limits of national sovereignty. Others assert that sovereignty should be defined in terms of the transition from aerodynamic lift to ballistic orbit. No matter how correct these approaches may be from the point of view of legal theory, they will surely strike our descendants as being childish games of a most appealing *naïveté*. No matter how sophisticated the arguments about national sovereignty, it should not be forgotten that individual national sovereignty itself is an ancient concept which may not survive the twentieth century—despite the present booming birth-rate of new nations. The increasing economic interdependence of nations, the 'explosion' of world population and the abuse of sovereign power—may ultimately lead to a dismantling of the extreme apparatus of individual sovereign power.

The essential activities which are in need of regulation are still human activities.[84] We cannot pretend to legislate for any other Intelligences who may be roaming through the universe. Therefore there is no need to postulate a new régime of law merely because we are able, for the first time, to poke through the thin layers of gas which cover the earth, nor need we establish a novel legal system for vehicles because they have rocket motors or can be steered beyond the moon. It would be just as sensible to have one set of laws to control murder indoors and another set for outdoors; or to argue that the International Rules for the prevention of Collisions at Sea could not be formulated or operated because there is no nation with sovereignty over the high seas.

That is not to say that there are no problems to be solved: there are many, but they are mostly of a familiar kind. For example, the United Nations Ad Hoc Committee on the Peaceful Uses of Outer Space[85] made several suggestions for immediate work:

1. The allocation of radio frequencies for space vehicles. (This has already begun.)
2. Liability for injury or damage caused by space vehicles.
3. Avoidance of interference between space vehicles and aircraft.
4. Identification and registration of space vehicles and the co-ordination of launchings.
5. Permission of sub-jacent states for re-entry and landing of space vehicles in the air space.

Topic No. 2 above is the only truly legal problem involved and can be tackled by a suitable extension of the scope and provisions of the 1952 Rome "Convention on damage caused by foreign aircraft to third parties on the surface."[86] Topic No. 5 can only be worked out in detail when there is substantial agreement on the other problems. *All the other immediate problems are essentially technical or scientific ones* and scientists should lose no time in addressing their minds to this task.

The International Astronautical Federation is to be commended upon its initiative in this field but so far appears to have designated lawyers alone for these tasks. No doubt the individual lawyers will collaborate with their scientific colleagues—but it would have been better if the various working groups[87] had a predominantly scientific composition, with perhaps a legal chairman. Unfortunately many of the American lawyers associated with the I.A.F., and led mainly by the eminent legal scholar Prof. J. C. Cooper, still regard the definition of sovereignty and the régime of "space law" as of paramount importance.

National sovereignty should be left where it is: a creation of the essentially earth-bound past: a monument to the horizontal limit of the imagination of statesmen. Strict ideas of national sovereignty have not prevented

82. Jenks. (1955) *op. cit.* p. 584.
83. *See* Col. Stone, *loc. cit.* in Note 22, Section 2.
84. *See* P. C. Jessup and H. J. Taubenfeld, *Controls for Outer Space and the Antarctic Analogy* (New York 1959).
85. 26 *JALC* 4, 385.
86. Cmd. 8886.
87. Established at the XIth Congress in Stockholm, 16th August 1960.

the U.S.A. and Canada from establishing identification zones for approaching aircraft which extend hundreds of miles over the high seas where no nation has sovereign power. Some American lawyers have even argued that the U2 flights over the U.S.S.R. were not in breach of international law, but it is not certain whether this theory would be upheld if the U.S.S.R. sent aircraft over the U.S.A. Satellites, I.C.B.M.s, moon and sun-probes have all been launched without any significant squeals of anguished sovereignty. In fact the pattern of the I.G.Y. scientific collaboration (now continued by COSPAR and CETEX), whereby the co-operating nations gave their tacit consent to satellite launching—is a very good indication that if the scientific problems are solved by scientists, national sovereignty can be quietly laid to rest. Determined work on the minimum necessary rules for the conduct of space activities can take place immediately. There is clearly little time to be lost: several purely commercial organisations are already in existence for the purpose of exploring space—*e.g.* in the U.K., Hawker-Siddeley and the British Space Development Co. Ltd. consortium. If national sovereignty *is* to be useful it can be used as the basis for the nationality of spacecraft, and for agreement to enforce the rules of space navigation by the State of Registry.

When multiple-crew voyages are possible it will be necessary to define the powers and authority of the vehicle commander. Work on this is already advanced at a more earthly level in the programme of the ICAO Legal Committee.[88] This Committee is also at an advanced stage with a convention on liabilities in the event of aerial collisions. If this is expanded to include spacecraft, military craft and the liability of traffic controllers, then it may be a suitable basis for allocating responsibilities between aircraft and spacecraft.

No major legal problems will be reached until it is necessary to consider landings on, and occupation of, extra-terrestrial bodies such as the moon. Again we have an earthly precedent: on the 1st December 1959, 12 nations (including U.K., U.S.A. and U.S.S.R.) signed a treaty dealing with Antarctica, describing the *peaceful* scientific activities which might be carried on there and, more important still, *suspending* any claims to sovereignty for the duration of the treaty. A similar treaty will be necessary to deal with all natural extra-terrestrial bodies—but it will be important not merely to *suspend* sovereignty claims (for that implies that sovereignty can be resumed) but to announce expressly that no nation is making any claim to sovereignty. It may be too much to hope that *all* the nations could agree to *renounce* all claims to sovereignty outside the earth. But the existence of a modified Antarctic treaty would ensure that with the passage of time, earthly sovereignty would wither as a concept for extra-terrestrial extrapolation. The U.S.S.R., which claims to have hit the moon's surface with a Soviet pennant, expressly disavowed any accompanying claims of sovereignty. Lord Hailsham, for the U.K., has *renounced* any U.K. claims to sovereignty on the moon. Although cynics may declare that this is merely a declaration of impotence, it is to be hoped that the wisdom and restraint of the U.K. and the U.S.S.R. may be continued by all nations.

Why has the U.S.A. been reluctant to follow suit? There can be little doubt that their underlying caution is dictated by a desire to preserve the inherent right of all nations to defend themselves in the event of attack (Article 51 of the United Nations Charter). Nevertheless, a report[89] submitted to the U.S. House of Representatives contains some of the most sober advice available so far on how to tackle coming problems. For example, the report recommends that the development of rudimentary space law should proceed by agreeing only *principles* initially in the most urgent and fruitful areas, and that this may be done by emphasising "agreements on scientific and commercial uses of space, working from there toward the larger issues such as national sovereignty."

War exists in the minds of men on earth and no nation with warlike intentions will be inhibited by agreements on the peaceful use of either the Antarctic or outer space. History may very well show that the use of words like "peaceful" and the concept of "space" as a separate region of law are simply acts of unsuspecting international self-deception.

This is the golden age for space lawyers and may be compared to the discussions on 'freedom of the air' which preceded the Paris Meetings of 1910 and 1919—all of which were marked by a vivid apprehension of the air as yet another frontier to defend.

Undoubtedly the combined efforts of the world's lawyers, politicians and scientists may be necessary to enjoy the age of exploration beyond the earth[90]. The noble richness of each writer's dreams of Utopia in space symbolises discontent with affairs on the earth: at the worst this may be no more than individual catharsis; at the best it may be capable of fulfilment. Whether it is waged with the Roman short "sword of courage" or X-bombs from space, the essential evil of war remains to be conquered on earth.

6. General Conclusions

After such a widely-ranging discussion it is tempting to emerge with some impressive principles for the guidance of mankind. The views which follow are the result of an unsuccessful battle with temptation, but they are offered in the full knowledge of their human frailty, incompleteness and arrogance, in the hope that they may suggest stimulating lines of thought to other members of the Royal Aeronautical Society:

1. Traditionally there has been little opportunity for direct consultation with scientists in the evolution of law. In the past, lawyers have been expected to bear, unaided, an unfair share of the burden of law-making.

88. *See also The Aircraft Commander in Commercial Air Transportation* by M. S. Kamminga. (Nijhoff, The Hague, 1953).

89. *Survey of Space Law*: Staff Report of the Select Committee on Astronautics and Space Exploration. House Document No. 89. (U.S. Government Printing Office, Washington 1959).

90. *See* in particular the excellent paper by C. W. Jenks "The International Control of Outer Space", presented to the Third Space Law Colloquium of the IAF, Stockholm, 16th August 1960.

2. In aeronautics this has had the result that the rules of law can often act as a serious limiting operational parameter—particularly for supersonic aircraft.
3. In aviation accidents, the operation of rules relating to legal liability can often throw a financial responsibility onto sections of the community which may be blameless from a scientific point of view.
4. Unless changes can be made in the laws associated with aeronautical activities many scientific members of this Society may find their future livelihoods at stake.
5. Scientific "operational research" could usefully be applied to the evolution of future aeronautical law.
6. Detailed rules governing aeronautics should not be mere catalogues of prohibited evils from the past, but should positively encourage a rational approach to the conduct of aeronautics.
7. For example, infringement of aeronautical rules should not necessarily be a crime EXCEPT in key matters—such as flying WITHOUT a licence or a certificate of airworthiness. All other matters could be in a *readable* "operations manual"[91]—infringements of which would initially result in the return of the delinquent for further education and training. So long as the aeronautical authority retains the right to withdraw the basic licences and certificates and prevent flights at any time—this is the most powerful type of control which is ever required.
8. Lawyers are at their best in describing and analysing the state of the law, in the weighing of evidence and in the fight for the preservation of essential human liberties and dignities. Acting alone, by training and experience they are more likely to apply established legal principles to new problems than they are to examine the need for new principles.
9. To avoid strangling the future of aeronautics with the noose of ancient thought, embodied in our law, scientists, lawyers and law-makers must find ways of collaborating effectively to identify essential problems and evolve creative solutions.
10. Failure to do this may have the gravest consequences when preparing the way for explorations beyond the earth.

There are indications that the broader problems of integrating the scientist into society are already well appreciated outside the sphere of aeronautics. As an example may be quoted the well-known but mysterious Pugwash International Conferences of Scientists of which the Sixth was held recently in Moscow.[92] Remarks of the distinguished novelist Sir Charles Snow seem to be particularly appropriate: he refers to politicians as "masters of the short-term solution." Scientists "have it within them to know what a future-directed society feels like, for science itself, in its human aspect is just that. That is why I want some scientists mixed up in our affairs. It would be bitter if, when this storm of history is over, the best epitaph that anyone could write of us was only that: they were 'the wisest men who had not the gift of foresight.' "[93]

Failure will be a new *trahison des clercs*.

7. Suggestion

From all the above, one single practical suggestion is made for the consideration of the Royal Aeronautical Society:

"That this Society should promote and establish (either within the Society or outside it) a Law Reform Committee or a Law Group with the general duty of applying Aeronautical and other Sciences to the evolution of law."

There are already in existence many groups representative of sectional interests—*e.g.* the Armed Forces, or the British Independent Air Transport Association who are able to present their particular viewpoint effectively. Members of this Society, in their capacity as members of a learned society, have no similar opportunity to add their contribution to aeronautical law-making.

The Chairman of such a Committee or Group should be legally qualified and, by way of example, could be drawn from the panel of lawyers accustomed to conducting public inquiries into aircraft accidents or could be experienced in international air law. The maximum number of members is probably best confined to six: not more than *four* scientists—two of whom should have senior high standing in research or the universities, the other two being younger men (not exceeding forty!), and *two* lawyers—at least one of whom should already have some acquaintance with aeronautics. All interested lawyers would be free to join in the work of the Group for specific purposes.

This suggestion is unlikely to cause difficulties in the status of the Society, its rules and liability to tax and rates. But if the idea is worth pursuing, then the difficulties are there to be solved, not relied upon.

In the past, this Society has had few doubts about its role in public affairs:

"By explaining what is being done, by discussing the conditions and possibilities of aeronautics, by securing co-operation between civil scientists and the Services, and by reminding Governments of their responsibilities, I believe this Society is doing very valuable and patriotic work."[94]

My suggestion is in fact in complete accordance with Clause 4(*i*) of the Charter of Incorporation of the Society (as amended) which shows as one of the objects and purposes for which the Society is constituted:

"to give the Legislature and any departments thereof and public bodies and engineering institutes and others facilities for conferring with and ascertaining the views of members of the Society and other persons engaged in the profession of aeronautics as regards matters directly or

91. Similar to the Ministry of Aviation's "Notes for the Guidance and Information of Applicants for an Air Operator's Certificate." CA Form 1238.
92. *The New Scientist*, 24th November 1960.
93. *Science and Government* by Sir Charles Snow. *Oxford University Press* 1961.
94. Rt. Hon. Lord Sydenham, F.R.S., 4th February 1914: XVIII *The Aeronautical Journal* 72, p. 312.

indirectly affecting Aeronautical Art, Science and Engineering and to confer, send representatives to and communicate with all or any such authorities and bodies in regard to the same."

Aristophanes knew what we could do:

"Is there any one amongst you O spectators who would lead
With birds a life of pleasure, let him come to us with speed
All that *here* is reckoned shameful, all that *here* the laws condemn
With the birds is right and proper, you may do it all with them."(95)

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However the inclusion of their names here should not be interpreted as meaning that they necessarily approve of the final form of any part of the paper—indeed it has been my privilege to differ respectfully from some of my friends. The views expressed are my own and do not necessarily coincide with any of the views of the British Aviation Insurance Company Limited.

Special thanks are also due to Mr. B. Harold Farmer, City Manager of Kissimmee City, Florida for a copy of their historic 1908 ordinance, and to Sir Charles Snow and Mr. Bo Lundberg for permission to quote from, at the time the lecture was given, as yet unpublished material. Finally I would like to acknowledge all the help I have received from the devoted staff at the Royal Aeronautical Society, and from Miss L. Gilham and Miss M. Sutcliffe —without whom nothing would have appeared !

As a postscript it is worth recording that principally due to the enthusiasm of Mr. Walter Tye, Mr. A. W. G. Kean, Mr. L. A. Wingfield and several other distinguished supporters, the idea of a Law Group within the Royal Aeronautical Society is taking shape.

APPENDIX A

« ORDONNANCE DE POLICE, 23 *Avril* 1784

« qui fait défense de fabriquer et faire enlever des ballons « et autres machines aérostatiques auxquels seraient adaptés « des réchauds à l'esprit-de-vin, de l'artifice et autres matières « dangereuses pour le feu ; et ordonne que tous autres ballons « aérostatiques ne pourront être enlevés sans avoir préala- « blement obtenu la permission.

« Du vingt-trois avril mil sept cent quatre-vingt-quatre.

« Sur ce qui Nous a été remontré par le procureur du Roi, « qu'il s'est fait à Paris et dans les environs plusieurs expé- « riences avec des machines aérostatiques auxquelles on adapte « des réchauds à esprit-de-vin, de l'Artifice et autres matières « capables de mettre le feu ; que ces Aérostats, dont quelques- « uns sont tombés dans les Tuileries, sur le quai des Théatins « et autres endroits, pourraient également tomber sur des « chantiers, dans des greniers et autres lieux remplis de « matières combustibles où ils pourraient causer des incen- « dies dont il serait difficile d'arrêter les progrès ; que pour « prévenir les accidents, il importe d'arrêter la fabrication et « l'usage de semblables machines, même de tous aérostats « que voudraient entreprendre et enlever des personnes sans « connaissances ni capacité ; qu'il lui paraît encore important « de faire précéder les expériences que voudraient faire les « personnes savantes et éclairées de permissions dont la « réquisition nous mettrait à portée de prendre au préalable, « les précautions nécessaires. Pourquoi il requiert qu'il y « soit pour Nous pourvu.

« Nous, faisant droit sur le réquisitoire du procureur du « Roi, faisons très expresses inhibitions et défenses à toutes « personnes, de quelque qualité et condition qu'elles soient, « de fabriquer et faire enlever des ballons et autres machines « aérostatiques auxquels seraient adaptés des réchauds à « l'esprit-de-vin, de l'Artifice et autres matières dangereuses « pour le feu. Ordonnons que ceux qui voudraient faire en- « lever d'autres ballons aérostatiques, seront préalablement « tenus d'en demander et obtenir la permission, laquelle ne « pourra être accordée qu'à des personnes d'une expérience « et d'une capacité bien reconnues, et contiendra le lieu, le « jour et l'heure auxquels pourront être faites lesdites expé- « riences ; le tout à peine contre les contrevenants de cinq « cents livres d'amende.

« Mandons aux commissaires au Châtelet, et enjoignons « à tous officiers de Police de tenir la main à l'exécution de « la présente ordonnance qui sera imprimée, publiée et affi- « chée partout où besoin sera.

« Ce fut fait et donné par Nous Jean-Charles-Pierre Lenoir, « chevalier, conseiller d'État, lieutenant général de police de « la ville, Prévôté et Vicomté de Paris, le vingt-trois avril « mil sept cent quatre-vingt-quatre.

« LENOIR.
« DE FLANDRE DE BRUNVILLE. »

« *Paris, le* 21 *août* 1819.

« Nous, ministre d'Etat, préfet de police.

« Vu le paragraphe 5 de l'article 1er du titre II de la loi « du 25 août 1790 ;

« Vu également la lettre de S. E. le ministre secrétaire « d'Etat de l'Intérieur, en date du 20 de ce mois ;

« Voulant prévenir les accidents plus ou moins graves et « notamment les incendies qui peuvent résulter des expé- « riences aérostatiques.

« Considérant que, dans le nombre de ces expériences aéros- « tatiques, celles en particulier des ballons dits montgol- « fières, et en général de toute espèce de ballons qui s'en- « lèvent par l'effet d'un foyer quelconque suspendu au-dessous « de l'orifice, présentent de grands dangers pour les maisons « et les propriétés.

« Ordonnons ce qui suit :

« 1. — En quelque temps et en quelque lieu que ce soit, « l'usage des ballons aérostatiques dits montgolfières, et en « général de tous ballons qui s'élèvent par l'effet d'un foyer « suspendu au-dessous de leur orifice est formellement interdit, « soit que l'aérostat dût être lancé à ballon perdu, soit qu'il « dût être tenu en ballon captif.

« 2. — Il est défendu de faire partir aucun aérostat qui « ne soit muni d'un parachute, et le départ du ballon n'aura « jamais lieu plus tard que dans la dernière heure qui précè- « derait le coucher du soleil.

« 3. — Les ascensions aérostatiques sont défendues jus- « qu'après la rentrée des récoltes.

« 4. — Les contraventions aux dispositions ci-dessus seront « constatées par des procès-verbaux dont il sera fait envoi « aux tribunaux pour les poursuites à exercer envers les « contrevenants, conformément à la loi.

« 5. — La présente ordonnance sera imprimée et affichée. « Exemplaires en seront envoyés à tous les entrepreneurs de « jardins publics, pour qu'ils aient à se conformer aux dispo- « sitions qu'elle renferme. Exemplaires en seront pareille- « ment adressés à MM. les commissaires de police et à MM. les « maires des communes du ressort de notre préfecture, et à « M. le colonel de la ville et de la gendarmerie royale de Paris, « à M. le commandant de la gendarmerie du département de « la Seine et à l'inspecteur général de police pour, par eux, « être surveillée l'exécution de l'ordonnance, chacun en ce « qui le concerne.

« Le ministre d'Etat, préfet de police,
« Comte ANGLÈS. »

From *Le Code de l'Air* by Gaston Bonnefoy, published by Marcel Rivière, Paris, 1909 (pp. 156–159).

95 From *World Drama* by Allardyce Nicoll (Harrap).

APPENDIX B

LAW IN THE AIR

A MOMENTOUS PROBLEM FOR LEGISLATORS

There can be no doubt but what a very intricate problem is now confronting us regarding the amending and making of laws to regulate that traffic which some of us believe will soon be darkening the air above our heads. But although apparatus has been constructed, tried, and proved successful and under perfect control, wherewith man has been carried through the air for hours on end, yet there are still many who are sceptical as to the probability of aerial navigation becoming a practical means of transport in the immediate future. Believing as I do that this question is one of great importance for our legislators to consider, I will explain why I think it likely to come to the fore so shortly. It may be several years yet before we shall all be going about in "air-cars," but our law-givers must ponder over the matter and devise new laws, and, moreover take means to carry them into effect before that time, else we shall suddenly have presented to us incidents difficult to deal with, and misdemeanours unrecognised by existing laws.

Though it seems hardly to be expected that propelled balloons will become very common, on account of the great expense which must always be incidental to their employment, yet machines of the Wright or Voisin type, involving comparatively little outlay and of so much smaller a size, seem likely soon to become of frequent utility.

Prophecy is a dangerous game to play at, but looking ahead is a most necessary proceeding, so, in the hope that it may convey some hints to those meditating the times to come, I will hazard a forecast of what I believe we may experience in the next few years.

During this year of grace, 1909, I expect to see new records cheated with aeroplane machines and new devices brought forward for their improvement; we may have flights of three or four hours' duration; journeys of over a hundred miles through the air: the Channel will very likely be crossed, and I certainly hope that Englishmen will not be behindhand in producing good appliances.

The year after should show further developments, especially as regards the number of machines. Abroad there may be scores of them; fifty machines of the Wright type are even now supposed to be in course of construction. Exciting races will undoubtedly take place, and cross-country journeys will often be performed. Military machines will certainly be to the fore, and will be attractive features at field-days and reviews. Experience and development are sure to result in the production of more practical appliances, able to stem the gales and to start from any piece of ground.

About the third year from now most people in England will have seen a flyer in the air, and a great many of the more adventurous ones will have made a flight. Aerial racing will have become an established sport, and cross-country journeys will be common. There would probably be thirty or forty machines in England, and they would then be much commoner than balloons are to-day. Cross-channel trips would certainly become the object of the ambition of each novice in turn.

At this rate, in four years time we may be able to say that flying is common. It may perhaps still be looked upon as a somewhat venturesome practice, and among the general community may not be exactly an every-day experience, but most well-to-do people will have made a trip, and many will own machines and make almost daily runs. It will be "quite the thing" to take your friends for a fly.

And this brings us to the time I wish to portray. It is then that the need of new laws and regulations will have to be adopted. There are several important questions that call for solution. The Rule of the Road in the air must be settled as also the question as to whether International frontiers are to be respected, and if not, whether universal Free Trade must result. Then comes the subject of the ownership of the air above private

property. Finally we must consider the means by which laws may be enforced, and the registration and identification of aerial machines carried out.

Aerial navigation by means of machines on the aeroplane principle ought, despite what is often said to the contrary, to be a very safe mode of locomotion. Ignorant people conjure up possible disasters which in reality are very unlikely to occur. For a machine to *collapse* in mid-air is extremely improbable when experience has taught us the requisite strength of the various members. It is no more likely than that a motor-car or a railway-train should fall to pieces; indeed, considering the shock and strain which these latter have to withstand in travelling on the ground, much less likely. A *stoppage of the engine* ought to have no bad effect beyond the possibility of an awkward landing should the ground underneath at the moment be unsuitable, since the large spread of surface allows the plane to glide down gently to earth. *Running into trees or buildings* could only be due either to a breakdown of the steering gear, again dependent on proper construction, or to bad steering on the part of the steersman. The capability of the aeronaut is undoubtedly of great importance. A mishap in the air, when it does occur, is liable not only to have very serious consequences for the machine and its occupants, but may also do considerable damage to persons and property below. It will therefore be very necessary to establish certificates of competency, which would probably be issued by the Board of Trade or such other body.

The only other accident that seems likely to result in serious consequences is *collision* with another machine. This must be provided against by careful provisions of the Rule of the Road in the air. On a terrestrial highway when two vehicles meet the necessary action is simple enough; both must go either to the right or to the left. But as applied to aerial machines there is a difficulty even here, for in some countries the rule is to go one way, in others the opposite. The laws for aerial navigation must be universal.

With marine vessels the matter is more complicated than on the road, since ships meet not only end on, but frequently at an angle. The same will occur in the air, and in fact the cases are so similar that it would seem undoubtedly the simplest plan to apply

maritime rules as far as they apply. Steering in a vertical direction may be used with airships, but at present it seems impossible to lay down laws regarding this, and the right and left movement should be sufficient at first. The actual application of such rules must be so dependent upon the practice and methods that it seems hardly possible at the present juncture to say much more. Let maritime laws be complied with until other modifications are found to be desirable.

International Frontiers.—Hitherto international frontiers have been fixed by natural divisions of land and water, such as the sea coast or river bank, or else, when such do not exist, by artificial fences or clearly defined strips of ground. Such lines of demarcation are not easily crossed by those who wish to do so unseen and without interruption. But in the air it is different. Here no natural boundaries exist, nor can artificial obstructions be erected so as to be insurmountable by airships. We are then called upon to answer a most vital question. Are aeronauts to be allowed to traverse these frontiers without let or hindrance, or must they descend at frontier stations to report themselves? If the former, many laws and regulations now in force would be affected. Those regarding passports, alien immigration, and the like would be seriously upset, but these are, perhaps, of no such very great importance; they are easy to evade as it is by those who like to run the risk, and the chance of heavy penalties for non-compliance with them might form a sufficient deterrent. But a far more serious matter is that of the collection of Customs. Even supposing it were not practicable to convey large cargoes of goods, and there is no good reason why this should not be done some day, still it would undoubtedly be possible to carry parcels of 100 pounds or so. If such an amount can be taken through the air free of duty, it would manifestly have to be allowed equally to land travellers. Considering, too, the rapidity and ease with which machines are likely to travel, they could be employed continually going to and fro over the frontier, and so transporting large quantities of dutiable goods.

Either Customs must be entirely done away with (except possibly as regards heavy and bulky goods, such as coal or corn) or we are faced with the second alternative, that is that all aerial vessels must descend at the Custom house to declare their cargo.

Though in the ordinary way it might be possible to enforce this by the imposition of severe penalties on any one detected in evading it, yet so great would be the opportunities for smuggling, especially in the dark or in misty weather, that it would without doubt be easy to ply the nefarious trade. The air-going smuggler would not be bound, as with his maritime prototype to land at a favourable spot on the coast; he could travel far inland before disembarking. Smuggling would undoubtedly become so lucrative an enterprise that it would become common and almost impossible to entirely prevent. To allow frontier guards to fire on all machines attempting to cross would hardly do, since the crossing might often be accidental. If, on the other hand, blank charges were fired to warn the aeronaut to come down, they would not have the desired effect on the "gun-runners" travelling at a very rapid pace and risking the effect of a second shot, which could not be sent for some seconds after the warning. Then, again, the airships might, conceivably, pass high overhead and out of shot, or could pass unobserved in the night. The very idea of such frontier guards, too, seems almost impracticable; they would have to be posted at every few hundred yards along the entire frontier. It has to be remembered, too, that the crossing of a frontier does not necessarily imply that the vessel is going to descend in the country it approaches. For instance, a British machine going to Germany might want to cross over parts of Belgium and Holland.

Altogether, it seems as if it would be impossible to enforce any law as to machines being compelled to descend at a frontier, and this implies that Customs, in the main, will have to be abolished.

But this simple statement that Customs must in future be dispensed with, involves a matter of the most supreme importance. As regards Great Britain, our revenue from imports amounts to something like £33,000,000 per annum, and if we wipe out this sum with one stroke of the pen, what are we to substitute in its place?

Here is a point having an important bearing on that great topic of the day—Tariff Reform. As a matter of fact, however, the main arguments of that refer chiefly to wheat, timber, and other imports which are not likely, at first, to be affected by

aerial transport. Indeed, it would almost seem that a tax on such commodities would be the solution to the difficulty of being unable to continue the duties on tobacco, spirits, &c.

This is a matter which must not be lightly set aside. The time may come, quite suddenly, when we shall find it impossible to collect dues. As soon as ever machines are constructed capable of crossing frontiers unobserved, a lucrative traffic will spring up, and from that moment the Customs receipts will rapidly dwindle to near zero.

Some, especially those who look upon the innovation as a curse, would suggest levying a heavy and almost prohibitive tax on all aerial machines. This, however, would hamper progress and stultify a promising industry. Moreover, it would necessitate an international agreement, since it would manifestly be suicidal policy for one country to impose a tax on its own machines if other countries did not do likewise.

Private Boundaries.—It has recently been pointed out by lawyers that according to law an Englishman's property extends upwards to the skies. To move through the air above is trespass; to shut out the owner's light is illegal. Yet, though the frequent passage of aerial machines over one's home will certainly be a great nuisance, it seems hardly possible to consider it an offence. That course would make aerial navigation almost an impossibility. And here again the law could never be enforced. Over the vast fields and woodlands of the country, who is there to prevent the progress of the airships? And, especially if they pass high up in the skies, who could find any valid objection to such traffic? With private gardens and buildings, and with machines skimming along a few feet above them, the case may be different, but where can the line be drawn? How can the aeronaut distinguish between a field, a park, and a garden? Probably no one would object if the track were fixed high up in the sky, but could the exact height be decided? A machine coming down to land may wish to descend gradually, or in rising may not be able to ascend quickly, and there may be other good reasons for wishing to keep low. A limitation of altitude would be quite impracticable without careful observation by means of some special instrument, both on the part of the aeronaut and on that of the landlord or policeman who brings the charge.

There would be more hard-sworn contradictions then than with the present speed limit for motor-cars!

Probably if no restriction be put upon the passage of air-cars over private property, some owners would like to construct wire fences on high poles in hopes of mitigating to some extent the evil. Such would no doubt give rise to much bitter feeling and might lead to nasty accidents, so the law must provide a clear pronouncement on this point.

Another important matter to be considered is as to whether an aerial machine should be allowed to land on private ground. It may be easy to pronounce it illegal, but this again would greatly hamper the use of the aerial highway, and there would be very frequent cases of accidental landings. In the case of the latter, or indeed any landings on private property, how can damage done be assessed? If a machine comes down in a field of standing corn it is evident that the aeronaut must pay for any destruction that he has wrought, yet he cannot be expected to at once hand over whatever the infuriated farmer may choose to ask. Some recognised system of insurance would probably be adopted.

Public landing-places would probably be provided by the municipalities in the vicinity of all towns.

As regards dropping articles from above, another most difficult question crops up. To throw out a piece of paper from an air-car does not seem to imply any very serious infringement of the law, and one could hardly tell whither, in its descent, the paper may travel. Yet it is evident that even bits of paper frequently scattered over a garden, for instance, would form a nuisance, and if this were to go unnoticed larger and heavier articles might likewise be discarded.

Then we must consider the case of enclosed grounds to which the public is admitted on payment, such as race-courses, cricket and football grounds, &c. It will obviously be impossible to prevent aerial travellers from hovering over such and watching the sport without payment. Still this is not likely to become a really serious matter.

Already the question has arisen as to whether aeronauts are at liberty to pass freely over fortifications, arsenals, and similar places hitherto forbidden ground. It would seem almost impossible to prevent them from doing so, and if they chose to take photographs as they pass, they can do so. As in the case of passing frontiers, it would hardly be politic to fire on machines, which may very likely be quite innocent of any prying intent.

In war-time it might be otherwise, but this encroaches upon a subject far too intricate to be gone into here. The conduct of war in the air-travelling period is at present a matter of mere speculation.

Policing the Air.—It is no good making laws without the ability to carry them into effect, and this is one of the greatest difficulties presenting itself to the would-be legislator of the airway. The answer to all the difficult questions which we have summarised may be said to depend entirely upon the possibility of bringing to book the lawbreakers.

Even supposing a regular service was inaugurated of police patrolling the air in extra swift flyers, they could seldom follow and catch up transgressors, since it would not often be possible to convey the "information" to them in time. There might be some recognised police signal, such as explosions of a "fog-signal," calling on a flyer to descend and report. But even this could easily be eluded.

Without any doubt it will be necessary to register all machines. They must have numbers or other means of identification assigned to them, and this also opens up a difficult problem. In order that the numbers can be discerned when at a great height it would be necessary to make them of a large size. If on the underneath of the planes they would not be visible when the machine was on the ground, and it might be difficult to see which way up they were supposed to be; for instance, whether a number was 8019 or 6108 and so on. In order to identify machines passing low their numbers might also be on their sides or vertical rudders, but it seems impossible to expose large figures to be visible from in front or behind, since any extensive surface would add so greatly to the resistance. By night, too, it would not be easy to arrange for the visibility of large numbers. Since it is probable that machines would frequently be passing from one country to another, some international arrangement would have to be come to to distinguish

the nationality of the car. This might be solved by the use of the national flag.

Considering the difficulty of displaying legible numbers, probably one of the best methods would be to introduce signal flags, as with ships. Such designs could be painted on the planes or other parts, and would be easily discernible. They would moreover, unlike ugly numbers, only add embellishment to the beauty of these graceful gliders. By a code of four or five flags with the national ensign at one end, every machine could be recognised. These might even be made transparent, so that, illuminated at night, they would always be visible though non-compliance with the rule could not be detected.

A question that must soon be decided is as to who will be the responsible authority for this registration and policing of aerial traffic, and for the certificates of competency. Shall it be the Board of Trade or the Home Office or will a new and separate Board have to be created?

B. Baden-Powell.

From *The National Review*, March 1909.

DISCUSSION

Walter Tye (*Chairman*): Mr Caplan had made it obvious that he was extremely well informed on his subject and that might make offering of comment a somewhat hazardous occupation. Nevertheless, the lecturer had put a great deal of effort into the preparation of his lecture and had tackled a difficult subject with courage, so his efforts should not be unrewarded by lack of comment, even though the scientific members of the Society might feel themselves on somewhat unfamiliar territory.

The lecturer drew attention to the fact that, in accident enquiry, scientific causation and the associated moral responsibilities, were often at variance with legal responsibilities or the legal liabilities. Did Mr. Caplan feel this was a matter which could and should be remedied? Perhaps the point could be put on two levels. Firstly, as regards the Warsaw Convention, this seemed to offer a quite surprising degree of protection to the operator, generally at the expense of the public. Broadly, the public had to prove wilful misconduct as the cause of the accident before they could claim beyond certain maximum figures. Proving wilful misconduct in an aeroplane accident seemed to him to be extraordinarily difficult. If the Convention were worded so as to give the public a better chance in substantiating their claims, did Mr. Caplan think this would provide a greater incentive towards aircraft safety? The second level was in connection with more detailed British law, the statute law. In aviation the safety of the vehicle depended on the combined efforts of large numbers of people. This being the case, a clear understanding of responsibilities was important and he included in this not only the overall division of responsibilities between operator, constructor, Government departments and similar agencies, but also the individual responsibilities between one man and another. At most accident enquiries, it seemed to him that the aviation fraternity as a whole was never very clear on its general or its individual responsibilities. He would like to illustrate this by a somewhat facetious but nevertheless factual example. In the Air Navigation Order a public transport aircraft might not fly in certain defined kinds of flights unless it carried at least 8oz. of glucose toffee for each person. If a hungry apprentice in the operator's organisation happened to eat one of the toffees, who went to jail? The implications of the Order were that the apprentice might certainly do so but the commander of the aircraft was another potential criminal, and so was the operator. They all had a fairly good idea who the commander of the aircraft was, but who was the operator? The Order described him as the person, who, at the relevant time, had the management of the aircraft. So it seemed in this slightly ridiculous example, that almost anyone, from the Chairman of the Company downwards was in for a fairly thin time. More seriously, however, this did indicate the importance of the exact definition of the responsibilities and exact allocation of them. He felt this not really so much from the viewpoint of who in fact suffered the penalty of the fine or the prison sentence, but because things were less likely to go wrong in the complex aviation organisation if the responsibilities were made clear to the individuals. He suggested there were two reasons for this, firstly to avoid one man or one organisation incorrectly supposing that another man or organisation had the matter in hand, and secondly he believed that the individual who was alive to a personal responsibility was more likely to conduct himself properly than if the decision were shared by an amorphous group of persons.

Mr. Caplan: First, the difficulties under the Warsaw convention of exploding the limits which were on the present price of gold, just under £3,000 pounds per passenger killed: one had to prove that *either* the air carrier failed to deliver a passenger ticket *or* that the carrier was guilty of wilful misconduct and that was the cause of the death, but he did not think that had any relation whatsoever to air safety. He thought that air safety was generally regarded as so important that it was dealt with completely separately and had no reflection in the field of legal liabilities. If the limit were, instead of £3000, £300,000, he did not think it would make any difference to air safety. He did think it would make a great deal of difference to the confidence of the travelling public if they found they had no rights of recourse or that their rights of recourse were limited to well below $10,000 which was a ludicrous figure by American standards. American claims were settled, if they were not governed by the Convention, to figures well in excess of these minute limits and those were the things which were threatening to upset the whole Convention. In areas where the standard of living, and the gross national product and so on was so high—everybody felt that a $10,000 claim was nothing, but he did not think there was any relationship between that and air safety. Nor did he think the air carrier needed the spur of unlimited liability in order to be mindful of air safety.

The other question he found fascinating: the effects of small infringements of regulations on the directors and the ordinary employees in an operator's staff. He thought this was a good reason why detailed rules of this nature should (*a*) not be incorporated in regulations and (*b*) not all be made crimes if one infringed them. Mr. Tye had illustrated the ludicrous results which arose. For example, he thought it would be perfectly satisfactory if a body such as the Air Registration Board were empowered to issue a comprehensive and comprehensible publication dealing with everything relating to air safety operations and maintenance. By itself, the omission of a glucose tablet should not be a crime. But on the other hand one would want to make it an offence to operate without a certificate of airworthiness. In other words, a graduated scale was needed; something between the full force of the law cracking down on the glucose tablet and the full force of the law being required to make sure one had an overall satisfactory organisation. He would like to see a lot of these things taken out of detailed statutory regulations which must produce headaches for parliamentary drafts men. The results were sometimes grotesque and quite inexplicable without reference to other bodies of knowledge. He thought it was sad that the whole process of subordinate legislation seemed to be developing more and more along these lines, but this was a general problem about which they in aeronautics could perhaps do little; but if they could pause from time to time and review what it was they were trying to do, they might point the way to less scientific sections of the community and, less scientific sections of the civil service. He could see no substitute, as yet, for the present scheme of both individual and corporate liability—not only in the field of regulation infringement, but also in the possibility of civil actions for damages.

Professor D. Goedhuis (Netherlands Embassy): Anyone who had been in contact with the problems of international aviation legislation in practice, would have much sympathy and would be in general agreement with the ideas on which the paper was based. He found it difficult to accept the first statement; Mr. Caplan said that the paper attempted to be neither scholarly nor objective. He thought it was a very scholarly paper and as regards objectiveness, the value of the paper was that it had indicated the extent to which solidarity in the world had been increased by the activities in the air and in space. One of these basic ideas was that the development of rules of law had failed to keep pace with technical development. This in itself might cause no great wonder since experience had taught that man's adaptability had never been able to react quickly enough to scientific discoveries, but one of the reasons why he thought the paper was of importance was that it acknowledged and indicated the wideness of the gap and it was a gap which was undoubtedly insufficiently realised. Mr. Caplan had given valuable examples on that

and he had thought of adding a few more but it would take too long as one could give hundreds of examples where passengers were prevented from travelling because of artificial restrictions.

Mr. Caplan criticised the principle of sovereignty and it was of course true that every succeeding scientific discovery made greater nonsense of old time conceptions of this principle but, perhaps unfortunately, they would have to live with sovereign states for a long time to come.

In the paper Mr. Caplan referred to Sir Charles Snow's remark about "The politician is the master of the short term solution." He did not think it was necessary to analyse why that was so, but it was enough to say that the scientists and lawyers had the task of making the long term interest prevail, and the great difficulty in which the law-makers and the scientists found themselves was of course that activities in the air and in space could not be divorced from international politics. The only possible thing which the scientists and lawyers and politicians, in co-operation could do was to make in the first place a profound study of the national interests which were involved in activities in the air and in space, and on the basis of that study, try to come to a common denominator and find the ultimate international interest which should serve as a basis for the rules which were to be made. The great problem in space was to weigh the ultimate interest and it was therefore essential, he thought to proceed with caution and not to lay down premature rules. One question which they all came up against, was how to segregate military from non-military uses of space. For instance, as regards the drawing of a demarcation line between the air and space, lack of agreement on that subject could, of course result in conflicts and uncertainty. Another question which arose was that regarding the freedom of transit of satellites, which was their orbit across a part of the air space over which the underlying state possessed sovereignty. Was the absence of protest by the underlying state proof of the initiation of a rule of innocent passage? Contrary to the opinion of some writers, he did not think that this question should be answered in the affirmative. The fact that up till now states had not protested against the flying of satellites over their territory at a height of ± 100 miles did not mean that states would not be *permitted* to protest.

A system of national defence based purely on physical distance seemed completely obsolete, but on the other hand one could expect, he was afraid, that states would most probably prefer to claim the greatest height practical as a limit of national space as long as there was no efficient security system. The International Law Association had been discussing these questions during their last conferences in New York in 1958 and in Hamburg in 1960 and one of the resolutions which was accepted at this conference was that the Secretary of the International Law Association was directed to submit to the United Nations a recommendation, one of the points being that according to the International Law Association outer space and celestial bodies should be utilised only for peaceful purposes and outer space should not be subjected to sovereignty or any other exclusive rights of any state. An international agreement was recommended whereby states would agree not to make claims of sovereignty or other exclusive rights over celestial bodies. He thought that it would be of great importance if the United Nations could in a not too distant future agree on a declaration more or less along the lines indicated by the International Law Association.

Mr. Caplan rightly refused to accept the political reality as an unchangeable element, and he was sure the audience would agree what an important task there was for the Royal Aeronautical Society to co-operate in the achievement of a deeper insight into requirements of the individual in air and in space, whatever his nationality.

Mr. Caplan: He thanked Professor Goedhuis for his careful observations and hoped that the Society took good note of his remarks. He was perhaps a little more hopeful than Professor Goedhuis about the implications of "no objection" from states to the orbitting satellites. He thought this a sign that states might continue to refrain from making sovereign claims in connection with other space activities, although at the moment this was no more than a pious hope. There was probably less hope of distinguishing between military and non-military uses of space and hence the only road to sanity might lie in efforts to internationalise the dissemination of scientific information from space activities.

H. Marking (B.E.A., *Companion*)*:* He did not think the Chairman's question and Mr. Caplan's reply about the liability limits under the Warsaw Convention should be allowed to rest without some further comment. Mr. Caplan said that a carrier's liability limit was now about £3000 per passenger, but pointed out that this limit could be broken in the case of wilful misconduct; he implied that this was a benefit wholly in favour of the carrier. But there was another side to the coin, which was that as a practical matter, because of the Warsaw Convention, a passenger who had suffered damage had to produce no proof of damage beyond proving his financial loss. The Warsaw Convention shifted the burden of proof, which was a most important consideration in practice which was wholly in favour of the passenger. Another point which should be mentioned was that some years ago a protocol to the Warsaw Convention was signed at the Hague, the Hague Protocol, which would have the effect of doubling the Warsaw limits to £6000 per passenger. There was at the present time a private Members Bill before the House of Commons for which the Government was to give parliamentary time; this Bill was being introduced at the insistance of the two air Corporations in order to give effect to the Hague Protocol in English law, although it would not become effective internationally until the required number of States had ratified the Hague Protocol and so far not enough had done so.

Mr. Caplan: This putting of the onus onto the carrier to prove that he was not liable, did make things much simpler for the claimant and it was in return for this that the carrier had some limit to his liability. What he thought had troubled Mr. Tye, and which had troubled him was that the imposition of the limit of liability did work unfairly sometimes and it was because of that it was tending to shake the whole useful structure of the Warsaw Convention. While in this country, £6000 or thereabouts would be available if Mr. Bell's Bill and all the other ratifications came through, in the United States, £6000 might still not satisfy a majority of claimants and there was a strong minority in the U.S.A. that wished to denounce the whole Warsaw Convention. This could upset any good that the United Kingdom might do by ratifying the Convention and the Hague Protocol. If this rising standard of living spread elsewhere some way might have to be found to preserve the broad scheme of liability under Convention and provide for more flexibility in its limits because it was really the limits which were under attack and not the scheme of liability under the Convention.

E. G. Ingram (Lloyds Aviation Underwriter): He would like to make a few comments about the Warsaw Convention. There was a tendency, he agreed, to ask for a larger sum in the event of a passenger being killed. But this extra money had to be paid for and usually it was paid by the insurance interests and if it came to pass that the Warsaw Convention limit of £3000 was increased under the Hague Protocol to £6000 it obviously meant that the airlines would have to pay more money for their passenger liability insurance. Passenger liability insurance rates were already fairly high but if they were doubled it meant that airline carriers would have to find the extra money charged by the insurance interests, which obviously would have to be passed on to the passenger and, in view of the fact that they were always hearing that airline travel was too dear and that fares should be reduced, this point should be borne in mind.

To give an example—in America where, of course, the Warsaw Convention limits did not apply to internal carriage, the legal awards for Passenger liability claims were

extremely high, amounting in some cases to $100,000, $150,000 and even $350,000 and consequently Passenger liability premium rates were often as much as five times that paid in this Country. It was therefore obvious that the larger the Passenger claim awards the larger the premium rates, which increase must eventually be passed on to the Passenger in the form of increased fares

Mr. Marking: B.E.A. in fact, did settle claims on an *ex gratia* basis at the moment, as if the Hague Protocol were in effect, and their experience had been that in the vast majority of cases which they had had to deal with, the proved financial loss had been less than £6,000 per passenger.

E. G. Fischeles (English Electric Aviation Ltd., *Associate Fellow*): How did Mr. Caplan account for the fact that, in spite of American aircraft insurance being so much higher than anything over here, they could charge a passenger-mile rate which was a fraction of anything in the U.K. or Europe?

Mr. Caplan: That was a question on airline economics which he did not feel capable of answering: "How potent is the factor of the passenger liability rate in the overall cost of transportation?" There were present people much more competent than he to answer such a question.

Mr Ingram had pointed out that any increase in liability limits would be reflected first in an increase in insurance premiums—which of course were ultimately paid by the airline passengers as revenue to the airlines. Part of the answer to Mr. Fischeles' point might be that the leading American carriers did have a very good loss record and many of them, in addition were able to carry substantial claims themselves before they sought insurance protection. For the best American operators therefore, the insurance costs were kept relatively low despite the high level of court awards.

It was interesting to hear of Mr. Marking's experience in claim settlements, although if they were on an *ex-gratia* basis they were, to that extent, not relevant to a discussion of strict legal liabilities even though they must undoubtedly represent a high standard of commercial prudence.

J. G. M. Pardoe (Air Registration Board, *Fellow*): This was just some mental arithmetic on the figures given by Mr. Ingram who, he understood suggested that to double the passenger insurance might cost £20 per seat per annum. On an aeroplane that flew 2,000 hours per annum this worked out at one hundredth of a pound per hour. This was the time taken to fly to Paris. He doubted if any passenger would wish to save twopence ha'penny extra if he could be assured of twice as much as the Warsaw Convention provided.

A. B. Hunter (British Aviation Insurance, *Associate Fellow*): They had heard recently of the controversial subject of the relative merits of JP4 and kerosine, and while he did not want to enter that particular field, where would the lecturer draw his line in the way of legislation needed for public interest? Also, who would he have make the decisions, the engineers or the lawyers?

Mr. Caplan: He would have neither engineers nor lawyers settle such questions on their own but he had great regard for such organisations as the Air Registration Board. Whether one chose to classify this as a combination of engineers or a combination of lawyers he did not know, but he thought it had to be an independent and a fearless authority; that was the only kind of body that could administer rules relating to safety, and he would say the question of how and where to draw that line would be a question of policy for such an authority. One had to draw a line, obviously, to decide what one was going to put people in jail for, and for what one was merely going to take away certain operating rights. He could not claim, here and now, to state a progressive policy for an operational air safety authority of the future, but he believed that lines could be drawn which could be rational lines, and they could only be drawn by an independent fearless authority.

R. E. Hardingham (Secretary, Air Registration Board, *Fellow*): He refused to be drawn by those few complimentary remarks, or to enter a discussion about JP4 versus kerosine. However, one of Mr. Caplan's conclusions was that the rule of law often acted as a serious limiting operational factor. He thought that was an exaggeration.

Governments had made two contributions to aviation. On the one hand, they made available public funds to facilitate aeronautical development and on the other hand they framed Rules. On the whole, he thought aviation had had a pretty good bargain. Having invested large sums of the taxpayers' money into what was possibly still a somewhat unnatural form of transport, it was at least understandable that the Government built up protective Laws of one kind or another. There might well be the usual percentage of nonsense in aeronautical law and Mr. Tye had given an example, but it happened in other law, and he had sufficient faith to believe that common sense in the end prevailed. He did not think that the nonsense would ever get to the point of seriously jeopardising the livelihood of aeronautical engineers.

Mr. Caplan said it was time scientists played a part in framing the laws. He agreed with this, in the over-all sense, that in a technological world, law-makers should have a proper grasp of that with which they were dealing. It would, however, be incorrect to suppose that training in scientific discipline automatically fitted a person to be a good law-maker. His activities in the Air Registration Board, which was at least on the fringe of statute law-making, suggested to him that the qualities required for good rule-making were fairly rare, and that they were no more to be found in the scientist than in any other section of the Community.

Mr. Caplan: In Mr. Hardingham's special sphere—the realm of airworthiness—he thought the combination of scientists, engineers and rule-makers was a particularly happy one. He had omitted to pay sufficient respect to the enormous achievements of Governments and law-makers in making this much that they had of aviation possible; his had been a great dirge of complaints and for that, he apologised. He had deliberately not painted the rosy side of the picture, but he had made some reference to it in the written paper, for example, the laws relating to the liability of the aircraft owner or operator for damage done by his aircraft. He thought this, and the way in which they had tackled legal liabilities for the nuisance of noise and so on, had been good examples for other countries. What he was concerned about was not that scientists had some magic or some exclusive prerogative which enabled them now to sit in a room with a slide rule and a few equations and produce the magical formula for the future. Their world was discovering things about the way men could think, and the way men could work in conjunction with each other so fast that it was time those disciplines were harnessed in the service of law making. He did not think scientists should be empowered to make laws for anybody any more that any other group of professional persons, but they did have access to a lot of useful knowledge and techniques in thought. All he was pleading was for scientists not to regard law-making and the law as always somebody else's job and for the other parties involved to pay more than lip service to the fact that there were other people in the world who might have something to contribute to the future of human conduct and rules for it. As to basic rules, he suspected they had not got much further than "Love thy neighbour as thyself." Rules of that nature, if only they were respected by all persons would make a lot of our present laws, lawyers, the law courts, police and prisons, unnecessary, but they were not so respected and he did not think they knew the reasons why. Why was it that some men knowingly never broke a rule in their life while there were others who seemed to derive their enjoyment in life from deliberately transgressing rules? He did not think they knew the answers to things like that but they must find out.

Professor A. J. Murphy (Principal, The College of Aeronautics *Fellow*): He took special satisfaction that a graduate

of Cranfield had for the first time given a Main Lecture to the Society and would also like to commend Mr. Caplan's scholarly address.

In view of the title, "The Law versus Science in Aeronautics," he came expecting to hear more about discord between science and law than in fact he had found in what the lecturer had said. He did observe, however, that Mr. Caplan's exceptional experience in the worlds of science, law and insurance had led him to believe that if there were differences it would take four scientists to hold their own against two lawyers on the committee which he proposed! It would be surprising if there were any basic conflict between science and the law. The aim of science had been described as "To search through all and reach the law within the law," which suggested a basic community of interest between the law and science. There was nevertheless one important difference. Law in the juridical sense was largely concerned nowadays with interpreting old laws in circumstances which were new and altogether different from those in which the legislation was first enacted. The courts adapted the old laws to new conditions but held on for as long as possible to the original principle and its enunciations. The laws of science were regarded in a different way and it was an article of faith with the scientist that in the light of new evidence he would always be ready to discard a law which up to the present he had fully accepted.

The law and science met in enquiries or litigation concerned with mishaps and catastrophes when technical matters were involved. The cause having been established beyond reasonable doubt by scientific investigation, the questions arose whether knowledge existed, the possession of which would have prevented this mishap occurring; ought the manufacturer or the operator to have been aware of that knowledge; and, finally, could he have been expected to recognise the relevance of that knowledge to the enterprise on which he was engaged? Remembering the vastness and complexity of modern science and technology those questions were sometimes difficult to answer.

They heard a great deal about public grievance against aircraft, on the grounds of noise. Noise, apart from being the alleged cause of harm to health, could be objected to on the grounds of damage to amenity. He sometimes wondered whether, one day, an aggrieved citizen might complain of the aesthetic damage done by the aeroplanes which disfigured a beautiful blue sky with vapour trails. Was there the possibility of such a person seeking a remedy for damage to an amenity which he previously enjoyed?

Mr. Caplan: He did not know and was open to correction, that destruction in those general terms of the amenities of a beautiful blue sky would give rise to any legal liability. If it were under the law of nuisance the private citizen would have to show that he had suffered some aggravation which was not suffered by the public at large. If Professor Murphy were referring to sky writing then he believed on the 1st January, 1962, that would be prohibited, together with other forms of aerial advertising. The mere appearance of aircraft across the sky should not give rise to any ordinary actions like trespass and nuisance, so one would have to dream up some entirely new limb of legal liability for the general aesthetic marring of the skies.

Dr. B. Cheng (University College, London): If he might follow in the wake of what had just been said about the title of Mr. Caplan's lecture, he thought that perhaps one should not oppose law to science or science to law. It was law and science or perhaps law with science that was really required in air law. Turning from one verbal comment to another, he would next question Mr. Caplan's definition of law. He was confining it to civil law. But there was the whole field of aeronautical regulations which were enforced by penal sanctions. In fact it was in regard to them that Mr. Caplan was making the interesting suggestion that isolated transgressions should not be punished. It almost reminded one of the saying that in law every dog had one bite!

Mr. Caplan had spoken of the "legal drag." But this was hardly the only interrelation between law and science in aeronautics. One might perhaps also think in terms of "legal lags," "legal quacks" and "legal tags."

In aviation, he thought that the trouble often did not consist in the law being an obstacle to the advancement of aeronautics. The law had, in fact, frequently lagged behind the achievements of aviation. Nowhere was this more apparent than in criminal law. The fairly recent case of *R.* v. *Martin* had shown, even though Mr. Justice Devlin did say that he did not wish the impression to be gained from that case that United Kingdom registered aircraft abroad were flying oases of lawlessness, that legislation was urgently required to extend the general body of English criminal law—in addition to what had already been done in the limited field of aeronautical regulations—to United Kingdom registered aircraft abroad, when they would otherwise be subject to the territorial jurisdiction of no state.

He would like to endorse what Mr. Caplan had said about legal day-dreaming. Especially in the field of space law, there had developed a fashionable school of thought which sought to escape from the ugly realities of life by drawing up blue prints for a Utopia in space. It hardly needed pointing out that there was no such thing as a space law orbiting somewhere in interplanetary or interstellar space. Space law was merely an extension of terrestrial legal systems to govern the relations between human beings in respect of what they would do in space. Therefore, unless there was a sudden change of heart in man, this space law was not likely to be any better or worse than the rest of man's law. Here, science, natural and political, as well as common sense would be most helpful in bringing the many amateur world reformers at present floating in outer space back to earth.

He would now turn to two types of tags.

First, the documents of carriage under the Warsaw Convention. Mr. Caplan had rightly pointed out that the present requirements imposed a tremendous burden on carriers. They might incur absolute and unlimited liability even for what might appear to be trivial omissions or inaccuracies in the documents of carriage, a penalty more severe than if they had been found guilty of wilful misconduct. But the Hague Protocol might have gone too far in the other direction. For, he submitted, *pace* Major Beaumont who, he thought, disagreed with this view, carriers might, under the Hague Protocol, refuse to register luggage, something which they could not do under the Warsaw Convention except in respect of small personal objects of which the passenger had charge. In cases where unregistered luggage was lost or damaged, the passenger had to prove negligence on the part of the carrier before he could claim compensation, whereas in the case of registered luggage the carrier's liability was presumed until the carrier proved the contrary. In this sense, the rules on documents of carriage in the Hague Protocol could work to the disadvantage of the passenger, although he was not suggesting that carriers would necessarily make use of this loop-hole if the Hague Protocol came into force. But the passenger would do well to watch for that luggage tag.

The second type of tag consisted in the law being used to hang the blame attaching to some unsatisfactory state of affairs. Thus the legal formulation of the right to fly for scheduled international air services which separated it into the various freedoms of the air was represented as a major obstacle in the liberal development of international air transport. He would be the first to agree that the use of the word "freedom" in this connection amounted to nothing less than a caricature, because every so-called new freedom of the air was in effect an additional restriction on the right to fly. But, in the first place, the concept of the freedoms of the air, whether divided into five, six, seven or eight, no longer played an active part in the present regulation of scheduled international air services by means of bilateral international agreements. Different and more generic formulae, such as "commercial entry and departure in international traffic," were used. Moreover, today neither the splitting up of the right to fly into various freedoms nor even capacity control

constituted the operative regulatory factor in the exchange of operating rights for scheduled international air services. Experience had shown that route fixing was the most effective and precise instrument. But the intense bargaining and frustration which surrounded the exchange of routes for scheduled international air services sprang not from lawyers, their terminology or the rules which they had been asked to formulate, but from the extreme nationalism, economic as well as political, of states.

There was no doubt that in the future development of air law, science must play an important part. But it was not only natural science, technology and jurisprudence, but also other disciplines which had now also assumed the name science, such as economics, sociology and political science. Those were all different branches of the study of man and society. Today human knowledge had become so specialised, fragmented and departmentalised that their society was not unlike an Indian goddess with ten hands. What one hand did, the other nine knew not. It seemed, therefore, that it was hardly by opposing one branch of knowledge to another that they could hope to solve the problems facing the legal regulation of aviation. If he might endorse what the lecturer had suggested, he thought an institution such as this Society should extend its reach and he would say that in the committee proposed by Mr. Caplan, not only did they need just lawyers and scientists getting together, but also representatives from other disciplines.

Mr. Caplan: He did admit that the title and the final suggestion were deliberately in opposition: the title was a description of the present state, his suggestion was a hope for the future and he agreed that as many disciplines as could be useful should be employed in the future evolution of law.

He was glad that Dr. Cheng had reminded him of the vast lawless areas opened up by *R. v. Martin* and he could only assume that the Government had a benign belief in the relative harmlessness of the majority of air passengers. Otherwise Parliamentary time would be found for an orderly extension of the scope of their criminal law into the air and following British aircraft wherever they might be.

With the greatest respect to his good friend he ventured to disagree with him on one effect of the Hague Protocol. He believed that once the carrier took charge of the baggage he must issue a baggage check.

He agreed with Dr. Cheng that route control was one of the most potent factors in the control of international air services, but capacity control was an undying force and this had to be notionally related to the 3rd, 4th and 5th freedoms.

Finally he must agree that many disciplines must share in future law-making and he hoped this might be implicit in the very wide terms in which he originally defined science. He might be excused for expressing the hope during a lecture to the Royal Aeronautical Society that specifically aeronautical scientists would be encouraged to play a part in future aeronautical law-making.

A Speaker: If an outsider might be permitted to make one brief remark on economic nationalism and perhaps the even more interesting question that Mr. Caplan asked, why it was that one man could keep rules and another man take pleasure in defying them.

Speaking as one who very recently flew in a very short time to many countries from here to the Far East and who was overwhelmed by the absurdity of having to have passports in each country: it had occurred to him that only by defiance of conventional law could there be a new discipline of the wider kind to which the United Nations would appear to be working. To make the point clear: if Mrs. Pankhurst for example, had been satisfied with the conventional law of her time, certainly no English women of today and probably few women of other countries would have the right to vote. It was fascinating to speculate, following H. G. Wells, whether people who were concerned with aeronautics, could so defy the conventional national laws as to bring about a broader, more enlightened, and wider kind of international discipline. This would make it obvious that many of the economic conventions to which they were obliged to conform, belonged not only to yesterday's world but perhaps to the day before yesterday. He would like to present that idea to this audience for serious consideration.

Mr. Caplan: On the best way of changing any rules and laws, his personal inclination was against anarchy and violence; he did not know whether one could chain oneself to the custom's posts of the world but undoubtedly they would have to find some way of ameliorating whatever they found irksome or unnecessary.

Mr. Tye: He thought that was a suitable note on which to close the evening and he would like to express, on their behalf, gratitude and appreciation to Mr. Caplan. He had the opportunity to glance at his script and noticed there were 95 references which gave some indication of the amount of preparation involved. Mr. Caplan could take comfort from the discussion which his lecture had given rise to—a discussion which he had anticipated might suffer from Mr. Caplan's phrase "legal-drag." Clearly it had not done so and, in fact, much more remained to be discussed. At least, they had left plenty of material for the Law Reform Committee, which Mr. Caplan had recommended, to interest itself in.

Major K. M. Beaumont (*Associate Fellow*), *Contributed:* Mr. Caplan seemed to suggest that scientists might be able to make a better job of the law and regulations in connection with Civil Aviation (both National and International), and relating to Outer Space, than Lawyers. His experience of the laws relating to Civil Aviation, which extended over thirty-six years, seemed to indicate that the Lawyers had not done so badly, and that the lack of progress in this field rested with Governments. The International Lawyers concerned had drawn up a number of Conventions dealing with Civil Aviation matters, and these had the approval of the technical experts and had had the approval and been signed by diplomatic representatives; but the Governments of even such diplomatic representatives had failed to ratify, and therefore bring into force, the Conventions concerned, except in the case of the Paris Convention of 1919, the Chicago Convention of 1944 (both ratified in periods of post-War optimism and enthusiasm), the Warsaw Convention of 1929, which was a practical measure forced upon Governments by International Air Carriers, and the International Sanitary Convention of 1933/46.

Mr. Caplan suggested that arrangements made internationally to permit of scheduled services traversing the air space of other States constituted a drag upon International Aviation, because those arrangements were subject to conditions; but if it were not for those arrangements, travel by the aircraft of one State through the air space of other States might be prohibited altogether. This seemed to be a case of about ninety per cent of a loaf being better than no loaf at all.

Mr. Caplan joined issue with Professor John C. Cooper on the subject of Space Law and Outer Space. He personally had agreed with Professor Cooper that, before they began to discuss the law and regulation of Outer Space, they should settle what was meant by Outer Space, *i.e.* at what height about the earth's surface this began.

Considering the problems which still existed and awaited solution in connection with aviation within the earth's atmosphere, it seemed to him that Mr. Caplan was optimistic in saying that "No problem will be reached until it is necessary to consider landings on, and occupation of, extra-territorial bodies such as the moon"; although he appreciated that, if Mr. Caplan's principles concerning renunciation by States of claims over Outer Space could be achieved internationally and universally, many problems would be solved.

There was a Special Committee of the United Nations dealing with the problems of Outer Space, which seemed to be proceeding slowly on the right lines.

Finally, it seemed to him that Mr. Caplan was being pessimistic when he suggested, in paragraph 4 of his general

conclusions, that "Unless changes can be made in the laws associated with Aeronautical activities, many scientific members of this Society may find their future livelihoods at stake."

Mr. Caplan: Powerful, yet courteous, dissent from an international air lawyer of Major Beaumont's standing was indeed an encouragement to any tyro in the field of air law. He could disagree with nothing Major Beaumont said but he did wish to disagree with the emphasis which he had given it.

He did not think that anywhere he had suggested that scientists *alone* could take over law-making in aeronautics. What he had done was to plead that scientists had got a special part to play in the legislative processes of the future and he hoped the Royal Aeronautical Society would find ways of doing this. It would be disastrous if any one section of society had the prerogative of making their voice heard in law-making. Citizens and legislators of the future would grow up with an increased awareness of science in the broadest sense. He hoped that aeronautics might be one of the earliest areas in which scientists, politicians and lawyers could collaborate effectively. Lawyers, of course, should be pre-eminent in the field of draughtsmanship.

It was indeed a tragedy that so many International Conventions remained unratified: the 1948 Geneva Convention, the 1952 Rome Convention and the 1955 Hague Protocol. Was this because they were imperfect? Or was it because they no longer satisfied the needs which were felt to be urgent long before they were signed? If the answer to either of these questions were yes—then this might be more of an indication of intrinsic defects in the Conventions, rather than an indication of the slothful nature of Governments. For example. the ICAO Legal Committee was already moving towards a Convention on Aerial Collisions which seemed to be condemned to comparative uselessness from the start because it neither included military aircraft nor the liability of air traffic controllers.

Major Beaumont suggested that one alternative to controlled entry for air services might have been complete prohibition. Although this was a legal possibility he suggested that it was a practical unreality—even if any State had been pig-headed enough to prohibit entry of foreigners for any purpose whatsoever. He was prepared to start from the present situation—whereby States imposed tortuous conditions on the entry of foreign aircraft for commercial purposes—and he would prophesy that gradually the conditions must diminish so long as peace continued and trade flourished. The European Free Trade Area and the Common Market were clear indications of the economic facts of life pushing age-old tariffs slowly on one side. Air commerce would surely follow in its wake. It was his hope that they could find ways of accelerating the process because he was convinced that the barriers which stifled freer air commerce were not really economic barriers, but the crude remnants of outworn sovereignty. At one time Trade followed the Flag. Today Trade shot holes through the Flag. The notion of sovereign independence was a wicked lie perpetuated by politicians who, with one eye could perceive the facts of international economic interdependence and could pretend with the other eye that there were some features of sovereignty which remained untouched—*i.e.* the right to tax individuals. He did not think the old ideas would survive this century, but he might be quite wrong in thinking that the process could be accelerated.

Why did it matter where Outer Space began? So long as they only had to legislate for human beings why should it matter where they were in order to enact suitable rules? If the Governments agreed that space-men and space-ships could not change their nationality merely by being shot into space—then all that was needed was agreement to continue to enforce national and international rules about their activities. Section 62 of the U.K. Civil Aviation Act 1949 and Article 76 of the Air Navigation Order 1960 seemed to be very good starting points. The physical problems of enforcement might be difficult—just as it was difficult to conduct aerial battles or eliminate aerial smuggling. But none of this so far as he could see called for a definition of where Outer Space began. But if one *did* define where Outer Space was for the purposes of sovereignty then one automatically created a lawless zone. Why create this difficulty? If it were attainable then the best idea was undoubtedly to internationalise space activities along Antarctic lines as suggested in the main paper.

His original text failed to make it clear that he meant "no major *legal* problems will be reached" until they had to consider extra-terrestrial occupation. For the reasons outlined above he still believed this to be so. Also in the original text he failed to make adequate reference to the work of the latest U.N. Committee (but he did refer to the report of the *Ad Hoc* Committee on the Peaceful Uses of Outer Space). He hoped Major Beaumont might forgive this omission. He had also included references to the scientific committees on Space Research and Extra-terrestrial Exploration (COSPAR and CETEX).

Aeronautical scientists were reaching a cross-roads in England if not elsewhere. Generations had grown up assuming that the world owed them a living. Many now found that the world at large was indifferent to their fate. One reason was that, as a group, they had been blind to the world in which they lived. An awareness of the part they could play in aeronautical law-making was simply one way in which aeronautical scientists could obtain some insight into the total environment around them. So far, very few scientists or lawyers had had any opportunity to *consider* this—let alone understand or agree with the main thesis. He believed most passionately that unless science and the law could come closer together—not only would scientists be the losers, but that the law itself must fall increasingly into disrepute. Sir Charles Snow (whose words he quoted in the concluding part of the paper) had sketched the problem on a much broader canvas when he feared that the epitaph of their age might be "they were the wisest men who had not the gift of foresight."

An Experimental Investigation of Base Flows at Supersonic Speeds

BY

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SUMMARY: Detailed measurements in the wake flow behind blunt based two-dimensional and three-dimensional bodies have been made at $M=2$. The results throw some light on the behaviour of separated flows and indicate the importance of flow reversal. The results for the two-dimensional body are in agreement with the Crocco and Lees' theory on separated shear flows. A preliminary study of the effect of air injection at the base shows that the base pressures increase significantly.

1. Introduction

The problem of the pressure acting at the base of a blunt tailed body moving at supersonic speeds is of fundamental importance in the prediction of its base drag. This pressure is determined by the mechanics of the wake for which there is as yet, no complete theory. In most cases the base pressure has to be determined experimentally. Several experimental investigations (Refs. 1, 2, 3 and 4), especially the work of Chapman, have shown how the state of the boundary layer formed on the body (Reynolds number) and Mach number, enter into the picture. Recently Crocco and Lees (Ref. 5) have developed an analytical approach for the treatment of dissipative shear flows interacting with the main flow. Their calculations seem to give the essential mechanism involved. In particular they show that mixing of the shear layers coming off the body with the outer flow is a fundamental feature of the process and must be taken into account in calculation of the base pressure. Crocco and Lees' theory however is based on several simplifications and extension of incompressible flow results. As noted by them, there is need for detailed measurements of the mixing of compressible, viscous flows. These would be of intrinsic value, as well as for the application to the base pressure problem. This paper reports some experimental observations of base flows which provide information of interest.

Transverse total head profiles and axial static pressure distributions in the base flow region behind a blunt based body of revolution and a two-dimensional body were measured. These throw some light on the mixing process and seem to confirm, in a general way, some aspects of Crocco and Lees' theory. In the case of the three-dimensional body the effect of injecting small quantities of air at the base was also studied.

NOTATION

M Mach number
M_x Mach number behind the base along the x axis
M_∞ free stream Mach number (before separation)
T temperature
T_0 total temperature
T_1 mean temperature in the shear layer
P_b base pressure
P_∞ free stream static pressure (before separation)
P_{bx} static pressure along the x axis behind the base
P_0 total head
ρ_∞ density of free stream (before separation)
ρ_e density of isentropic stream after expansion
U_∞ velocity of free stream (before separation)
U_e velocity of isentropic stream after expansion
U_1 mean velocity in the shear layer defined by $U_1=KU_e=I/m$
$w_1=u_1/a_s$ where a_s is the stagnation speed of sound
$K=U_1/U_e$
f parameter appearing in the mean temperature, mean velocity relation of the shear layer
m mass flow in the shear layer
I momentum flux
θ momentum thickness
δ shear layer thickness
m_i mass of air injected at the base
k mixing factor
x, y co-ordinates.

2. Experimental Set Up and Method

All the measurements were carried out in a 1 in. $\times$ 3 in. blow-down supersonic wind tunnel (*see* Ref. 6 for details). The three-dimensional body consisted of a 9 in. long, hollow, $\frac{3}{8}$ in. outside diameter, circular cylinder supported with its length along the axis of the tunnel. The upstream end of the cylinder terminated in a conical nose while the downstream end was closed by a replaceable cap of the same outside diameter with a static hole for the measurement of base pressure. The cylinder was mounted through the throat of the tunnel as shown in Fig. 1, in order to avoid the formation of bow shock waves. The hollow side support was also in the subsonic region and served either to communicate the base pressure to a mercury manometer or to bring in atmospheric air for injection studies. The two-dimensional tests were conducted on a 10 in. long, $\frac{3}{8}$ in. thick plate spanning the tunnel and mounted through the nozzle throat in a manner similar to the cylinder. Eleven pressure taps situated in the base region communicated the static pressure distribution to a multi-tube mercury manometer. The total head profiles in the boundary layer on the model and across the shear layers at various axial locations were measured by

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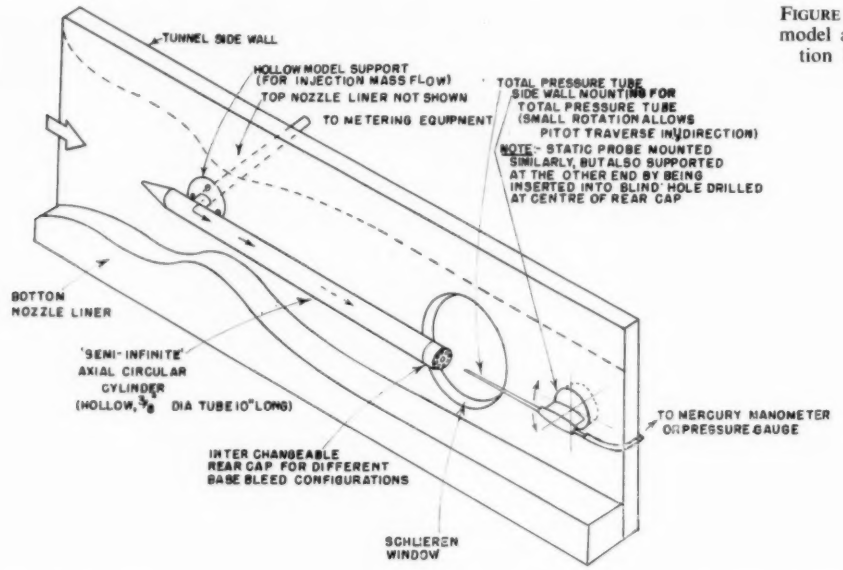
TUNNEL SIDE WALL
HOLLOW MODEL SUPPORT (FOR INJECTION MASS FLOW)
TOP NOZZLE LINER NOT SHOWN
TO METERING EQUIPMENT
TOTAL PRESSURE TUBE SIDE WALL MOUNTING FOR TOTAL PRESSURE TUBE (SMALL ROTATION ALLOWS PITOT TRAVERSE IN DIRECTION)
NOTE - STATIC PROBE MOUNTED SIMILARLY, BUT ALSO SUPPORTED AT THE OTHER END BY BEING INSERTED INTO BLIND HOLE DRILLED AT CENTRE OF REAR CAP
BOTTON NOZZLE LINER
'SEMI-INFINITE' AXIAL CIRCULAR CYLINDER (HOLLOW, 3/8 DIA TUBE 10" LONG)
TO MERCURY MANOMETER OR PRESSURE GAUGE
INTER CHANGEABLE REAR CAP FOR DIFFERENT BASE BLEED CONFIGURATIONS
SCHLIEREN WINDOW

FIGURE 1. Diagrammatic view of model and pressure probe installation in 3 in. × 1 in. tunnel.

means of total head tubes mounted on a fixture $4\frac{3}{4}$ inches behind the base. The fixture allowed axial positioning of the total head probes as well as rotation in pitch. All the probes were initially calibrated for errors in pitch. Inside the shear layers the incidence did not exceed five degrees and the maximum error due to this was below 5 per cent. A flat probe with a rectangular 0·06 in. × 0·02 in. opening was employed for the measurement of boundary layer profiles and a circular probe of 0·04 in. outside diameter was used for the shear layers. Static pressure distributions behind the base were measured by a static pressure probe of 0·04 in. outside diameter. The nose of this probe was always inside a sealed hollow sheath inside the model base. This prevented any vibration of the probe and also effectively eliminated any nose interference effects.

The injection experiments were carried out for the three-dimensional body only. The base cap was replaced by one having eight 0·025 in. diameter holes drilled on a circle at the base. In order to investigate the effect of hole position, caps with the same number and diameter of holes but at various radii were employed. Atmospheric air entered into the hollow cylinder through the side support via a metering system and a regulating valve. The injection mass flows were quite small and the size of the ducting sufficiently large to avoid any choking difficulties. Total pressure profiles and axial static pressure distributions were measured in the injection studies in exactly the same manner as described earlier. For the purpose of obtaining the overall configuration of the outer flow, the tail expansion fan, shock waves and the shear layers, several schlieren photographs and shadowgraphs were taken in each case.

The main experiments were conducted under the conditions shown in Table 1.

3. Experimental Results and Discussion

3.1. FLOW AT THE BASE

Figures 2, 3 and 4 show the detailed structure of the base flow in the cases studied. The configuration of the outer flow, shown in these figures, has been obtained from schlieren and shadowgraph observations. The boundaries of the shear layers as observed on the schlieren, approximately coincide with those indicated by P_0 measurements. The boundaries of the shear layers are assumed to lie where $\partial P_0/\partial y$ in the shear layer becomes negligibly small. The total pressure measurements in the shear layers have been plotted as Mach number profiles. These calculations were carried out on the assumption that at any axial station the static pressure is constant across the shear layers and that the total temperature throughout the flow including the dissipative region is the same. These assumptions are not strictly true but the errors involved are relatively small and the calculations can be taken to give a first approximation to the flow. Based on the Mach number profiles the following quantities of interest in the mixing process were calculated.

(*i*) Mass flow at any cross section of the shear layer (m).

TABLE 1

No.	*Model configuration*	*Boundary layer on the model*	*Injection at the base*	M	R_θ	R_x *calculated from* R_θ	R_x *based on length**	P_0 *lb./in.² abs.*	T_0
1.	3-dim. body	Laminar	Zero	1·95	6×10^2	$7{\cdot}16\times10^5$	$1{\cdot}12\times10^6$	38·3	27°C
2.	3-dim. body	Laminar		1·95	6×10^2	$7{\cdot}16\times10^5$	$1{\cdot}12\times10^6$	38·3	27°C
3.	3-dim. body	Turbulent	Zero	1·85	$2{\cdot}1\times10^3$	$1{\cdot}4\times10^6$	$1{\cdot}56\times10^6$	38·3	27°C
4.	3-dim. body	Turbulent		1·85	$2{\cdot}1\times10^3$	$1{\cdot}4\times10^6$	$1{\cdot}56\times10^6$	38·3	27°C
5.	2-dim. body	Turbulent	Zero	2·07	$1{\cdot}7\times10^3$	$1{\cdot}0\times10^6$	$1{\cdot}22\times10^6$	33·3	27°C

*The length is measured from the throat of the nozzle up to the base. For getting turbulent boundary layer the throat was shifted upstream by 2 in.

(*ii*) The mixing factor $k = \frac{dm}{dx} \Big/ \rho_\infty u_\infty$ where ρ_∞ and u_∞ are the free stream density and velocity respectively.

(*iii*) The total momentum flux in the shear layer I.

Figure 5 shows the distributions of the mass m and the momentum I. Certain aspects of Crocco and Lees' theory about the mixing process are later compared with the experimental results. Here we note that the measurements, especially the axial static pressure distributions, show that, although the velocities are small, there is flow in the so called "dead air" region. Downstream of the base, the static pressure at first falls and reaches a minimum and then rises again almost to the free stream value indicating a recompression region. In the beginning of this region there is a point in the static pressure distribution curve, where the pressure is equal to the base pressure. Since one cannot expect appreciable variation of total pressure near the base, the second base pressure point seems to indicate a stagnation region. One would therefore expect that a reverse or "feedback" towards the base is present. This second stagnation region is similar to reattachment point in the case of reattaching separated flows. Although such a condition does not exist in the present case, the second stagnation point indicates that the flow has decelerated considerably approaching stagnation. From the total head measurements in the shear layer it is difficult to pinpoint this region since measurements are unreliable in the reverse flow region. Figures 2, 3 and 4 show roughly the second stagnation regions as indicated by the static pressure distributions behind the base. (Since the assumptions made in the reverse flow are crude, there is some discrepancy in the location of the second stagnation regions as calculated from static pressure measurements and Pitot traverse.) Supporting evidence for the presence of the "feedback" process is provided by the Mach number contours of Figs. 2, 3 and 4 and the mass flow curves of Fig. 5. (In Figs. 2, 3 and 4 the Mach number curve—lower figure—has been drawn joining all the points smoothly.) The Mach number contours show the existence of an axial subsonic region of the flow behind the base extending well into the foot of the shock wave system indicating favourable conditions for feedback. Fig. 5 shows that under equilibrium conditions the mass of air which is removed from the base region by the action of the shear layers coming off the body (like a jet pump) is approximately equal to the mass reversed back into this region, from the high pressure region at the foot of the shock wave system. For the calculation of the mass flow m the integration is performed over the shear layer region between the heavy dotted lines shown in Figs. 2, 3 and 4. The initial increase of mass flow with distance downstream, in the shear layer is due to entrainment mainly from the "dead air" region and it appears as though the entrainment from the outer flow is relatively small. In Figs. 2, 3 and 4 the maximum mass flow occurs roughly half way in the recompression region. Further downstream the mass flow in the shear layer decreases, reaching almost the same value that it had at the base. This decrease is due to the mass carried into the "dead air" region by the reverse flow. While the present measurements cannot establish all the quantitative aspects of the problem, qualitatively the flow pattern appears to be as sketched in Fig. 6. Evidently the reverse flow is an important feature of the mixing process which determines the base pressure.

3.2. COMPARISON WITH CROCCO AND LEES' THEORY

In Ref. 5 a general relation between the static temperature and the velocity is developed for dissipative flows involving mixing. This is of the form

$$U_1 = U_e K$$

$$\frac{T_1}{T_0} = f - \frac{\gamma - 1}{2} w_1^2$$

Crocco and Lees show that a universal relation between the parameters f and K can be used to describe a very general class of separating and reattaching boundary layer flows. Fig. 7 shows the Crocco and Lees' f and K relation when applied to the two-dimensional base pressure problem for the turbulent boundary layer case of Fig. 4. The point B.L. represents the condition of the boundary layer before separation. Decelerating flows follow the $f(K)$ curve to the left of B while acceleration is represented towards the right. After separation the boundary layers become wake-like and theory shows that the curve tends towards a vertical tangent. In the present investigation the $f(K)$ relation was obtained from shear layer profiles measured in the case of the two-dimensional body. f and K were calculated from the definitions (Ref. 5),

$$f = \frac{P_{bx} U_1 \delta}{mR} \Big/ T_0 + \frac{\gamma - 1}{2} w_1^2$$

$$K = \frac{I}{mU_e}$$

where m and I are the mass and momentum flux in the shear layer respectively, U_e is the velocity of the isentropic stream, $w_1 = U_1/a_s$ (U_1 = average velocity in the shear layer defined by $U_1 = I/m$ and a_s is the stagnation speed of sound), P_{bx} is the static pressure along the x axis behind the base, δ is the thickness of the dissipative flow (boundary layer and shear layer), R is the gas constant in the equation of state and T_0 is the total temperature.

The $f(K)$ curve obtained from the measurements is also shown in Fig. 7. The location of each axial station where f and K were calculated is also indicated on the figure. While the experimental points do not lie very close to the theoretical curve, they do define a curve which has the general shape and features predicted by theory. The measured boundary layer point on the $f(K)$ curve is shifted to the right. This shift can be attributed to the upstream communication of the corner acceleration effects within the boundary layer. All the points corresponding to the expansion zone lie to the right of the point representing the boundary layer. The subsequent deceleration process is represented as predicted by theory with f rapidly increasing. Considering the several simplifying assumptions made in the theory and the

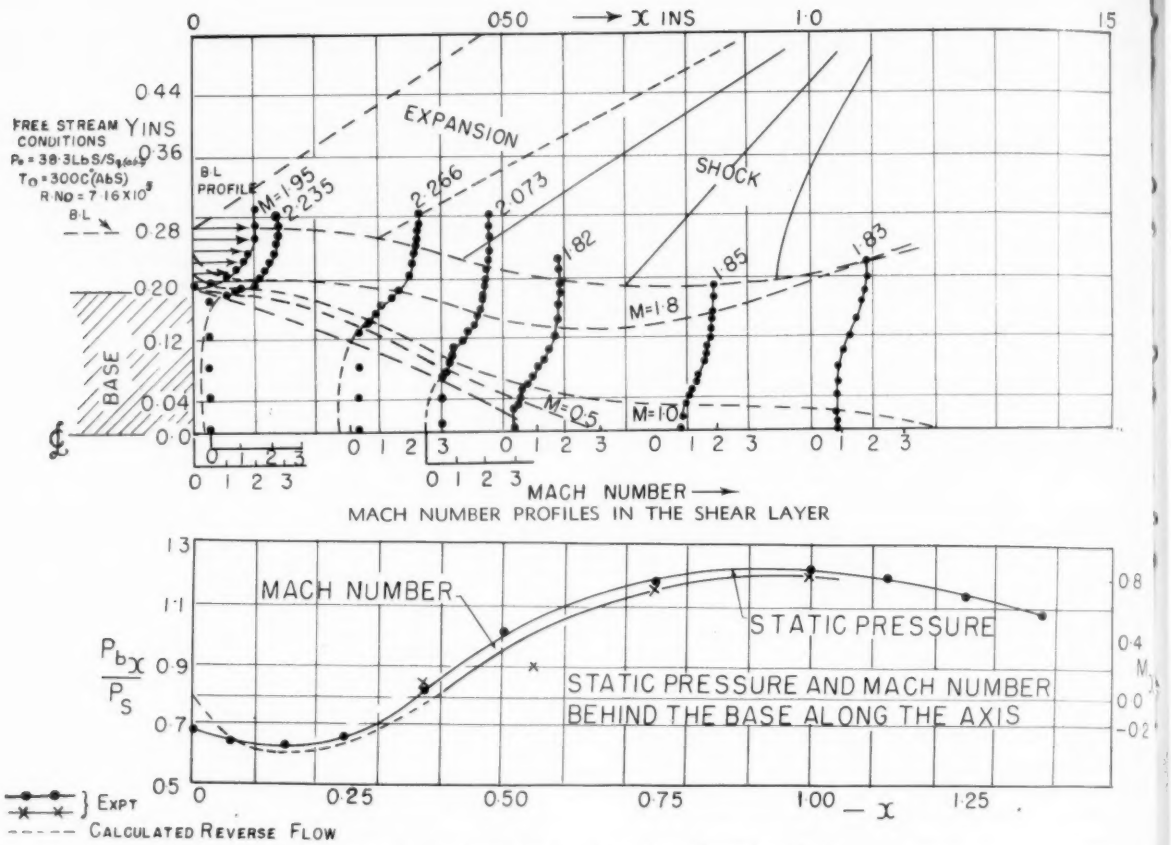

FIGURE 2. Laminar boundary layer three dimensional body.

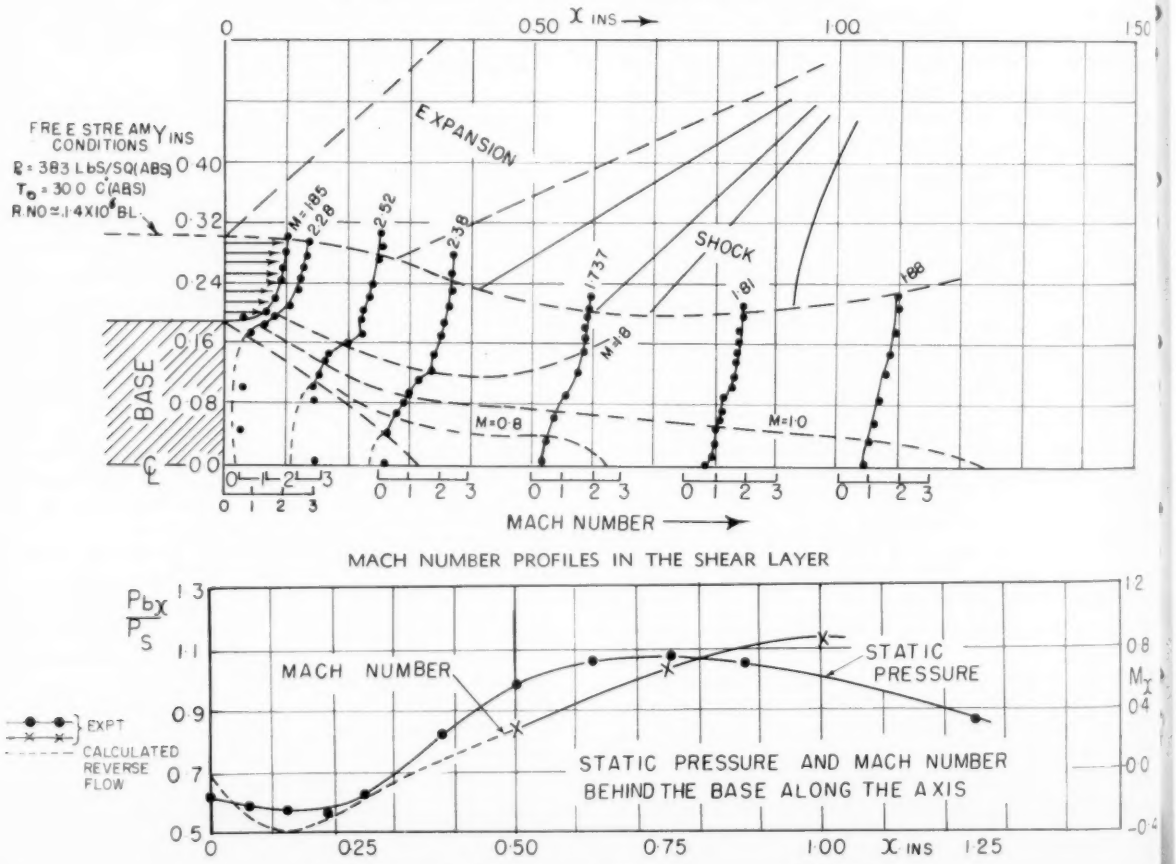

FIGURE 3. Turbulent boundary layer, three-dimensional body.

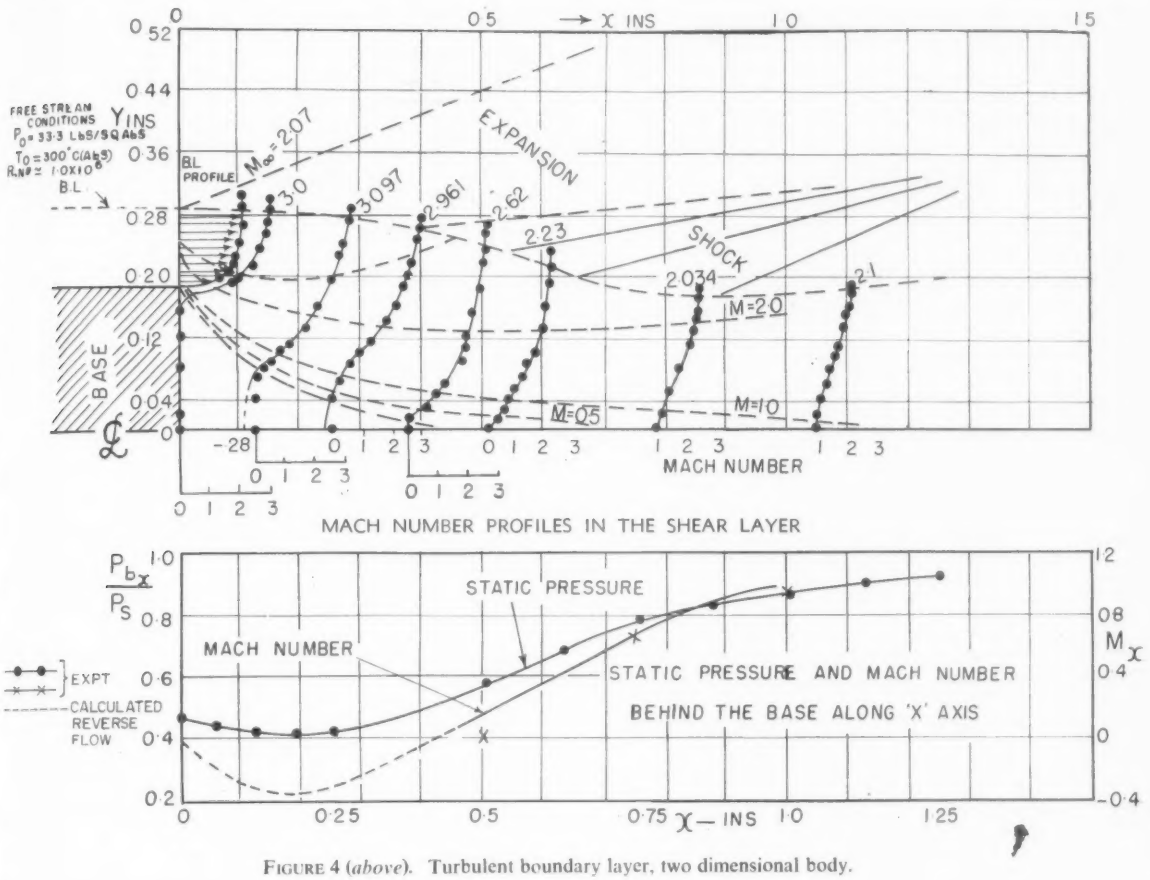

FIGURE 4 (*above*). Turbulent boundary layer, two dimensional body.

errors involved in the measurements, the agreement between theory and experiment is as good as can be expected.

Another factor which is employed by the Crocco and Lees' theory is the mixing factor k defined as $k = \frac{dm}{dx} \Big/ \rho_\infty u_\infty$. According to the assumptions made by the theory k is constant for the laminar as well as the turbulent mixing layers, its numerical value being ten times greater in the latter case. In the present investigation k was determined for the cases studied, from the profile measurements. The average values of this parameter over the region from the base to the shock wave region were found to be as shown in Table II.

TABLE II

Case	*M*	R_δ	(*k*) *experimental*	(*k*) *theory*
3-dimensional laminar	1·95	$1{\cdot}086 \times 10^4$	0·00729	——
3-dimensional turbulent	1·85	$3{\cdot}738 \times 10^4$	0·0279	——
2-dimensional turbulent	2·07	$3{\cdot}14 \times 10^4$	0·01308	0·03 (Low speeds) From Ref. 5

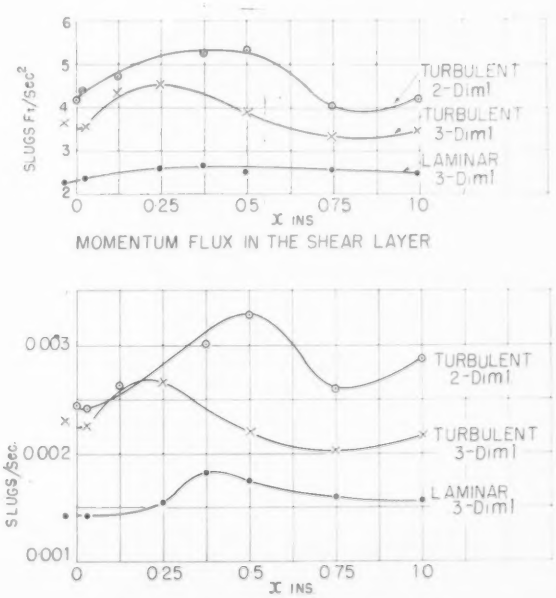

FIGURE 5. Mass flow in the shear layer.

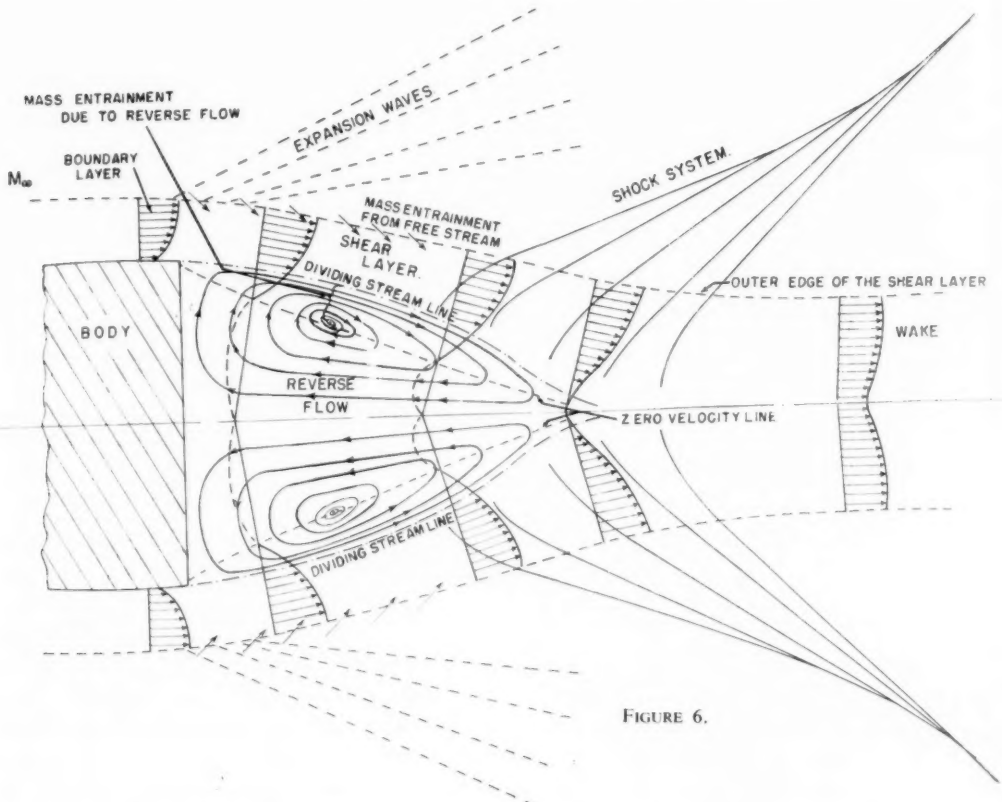

FIGURE 6.

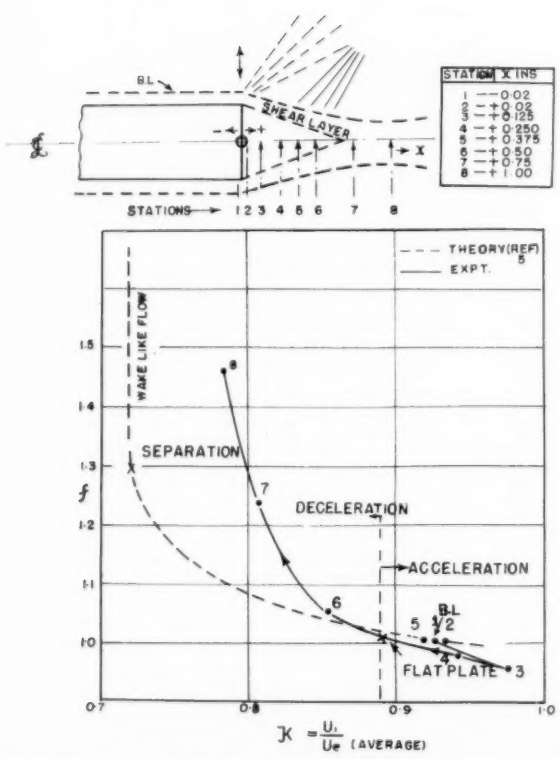

FIGURE 7. f–k curve for two-dimensional turbulent shear layer.

Actual comparison was not possible since numerical values of k are not predicted by theory, but the present measurements give an indication of the orders of magnitude involved.

3.3. EFFECT OF AIR INJECTION ON BASE PRESSURES

During the experiments it was noticed that the base pressure was very sensitive to small leaks of air into the "dead air" region. Since air injection can be expected to alter the mass of air involved in the mixing process, it was conjectured that this means could be employed as a method for further study of the base flow. Metered quantities of air were injected through small holes drilled at the base of the three-dimensional body and the base pressures, axial static pressure distributions and total pressure profiles were measured as described in Section 2. The effects of varying the position of the injection holes and the injected mass of air are shown in Figs. 8 and 9 for the case of the three-dimensional laminar and turbulent boundary layers studied earlier. Figs. 8 and 9 indicate that there is an optimum location as well as quantity of injected mass, for maximum increase of base pressure. The axial static pressure distributions were measured under the optimum conditions of hole location and mass flow. They indicate that injection affects the entire flow in the mixing zone. Fig. 10 shows the details of flow as measured for the case of the turbulent boundary layer with injection

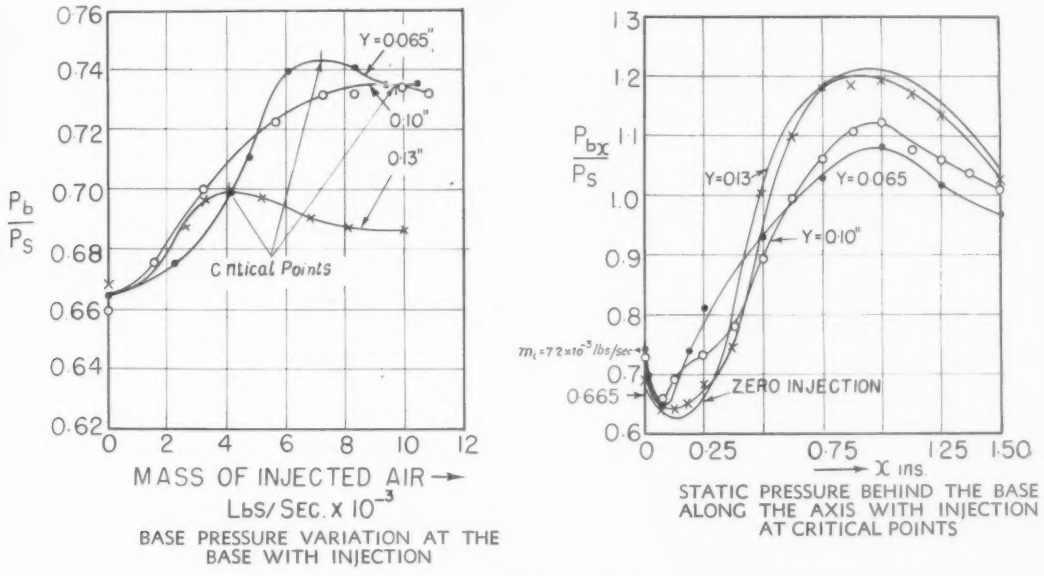

FIGURE 8. Laminar boundary layer.

Compared to the flow without injection the base pressure is seen to be 24 per cent higher and axial extent of the subsonic region greater while the pressure gradients in this region are less. The maximum reverse flow Mach number is higher. A rough calculation was made to account for the increased base pressure during injection on the assumption that the resulting base pressure is an average of the injected air acting at the holes, with the rest of the base being subjected to the original base pressure. This calculation accounted for less than 50 per cent of the observed base pressure rise indicating the importance of including the mixing process in determining the base pressure. Schlieren observations as well as the flow measurements show a shift of the main shear layers away from the central axis during injection. This is consistent with the increased pressure in the enclosed region. While the present work does not establish the flow mechanism by which injection affects the base pressure it does show the importance of the location and quantity of the injected air and broadly speaking, corroborates the importance of this reversed flow in the base pressure problem. Further work is necessary to explain the changes observed.

4. Conclusions

The following results have been obtained from the measurements:

(*a*) there exist subsonic regions behind the base of a

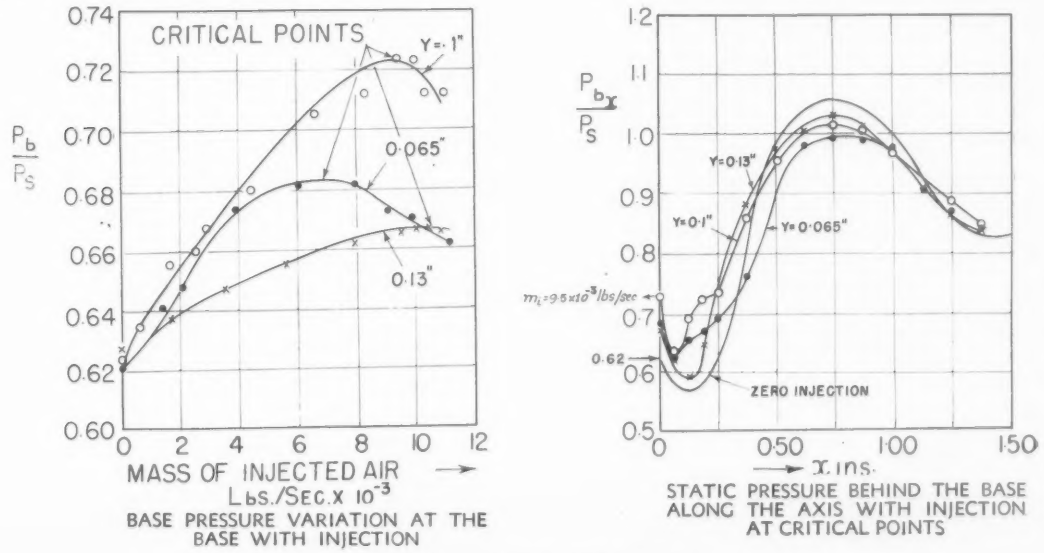

FIGURE 9. Turbulent boundary layer.

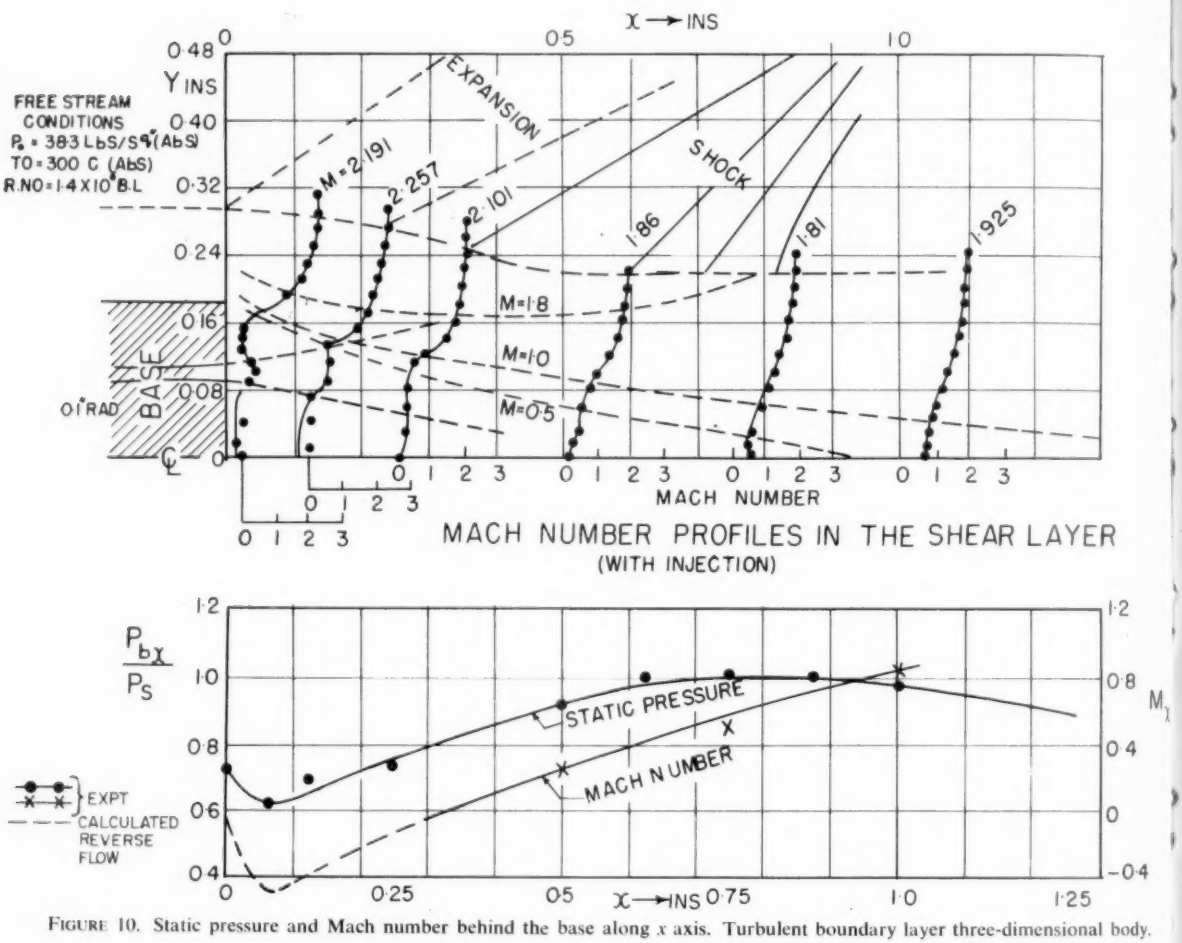

FIGURE 10. Static pressure and Mach number behind the base along x axis. Turbulent boundary layer three-dimensional body.

blunt-body in supersonic flow which extend up to the foot of the trailing shock wave system both for laminar, turbulent, three-dimensional and two-dimensional flows.

(*b*) The measurements indicate a reverse flow from the high pressure zone at the foot of the shock waves towards the base. The mass reversed is roughly equal to the mass sucked from the "dead air" region.

(*c*) Comparison of the experiments with Crocco and Lees' theory in the two-dimensional case studied confirms the behaviour of the $f(K)$ relation broadly, although the numerical values differ considerably from those predicted. For the cases studied the average values of the turbulent mixing factor show that it is nearly four times for the three-dimensional case as compared with the laminar case and more than twice the value for the two-dimensional case.

(*d*) Small quantities of air injected into the "dead air" region affect the base pressures significantly causing an increase of 21 per cent and 24 per cent in the three-dimensional laminar and turbulent cases studied respectively.

ACKNOWLEDGMENT

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An Appreciation of Missile Structures

BY

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1. Introduction

The invitation for this lecture requested "a review of missile structures from the viewpoint of an aircraft designer." This is inevitable because most of the author's experience has been associated with aircraft design. There are however many people actively concerned with missiles who have had considerable experience designing aircraft and would be better qualified to make a more realistic approach to the subject. The difficulty for an outsider making a review of missiles is justifying the "need to know" and then, having found out, or deduced interesting facts, he may be made aware that to publish them would contravene some security ruling.

The unfortunate thing about missiles is that although they evolved from the old concept of aircraft, the business of designing and building them has become a separate and distinct industry.

With the trend towards sustained supersonic flight for both missiles and aircraft, the design, structural, material and production problems are intimately connected and the technical separation of missiles and aircraft seems to be undesirable.

The present position of British missile firms is somewhat depressing, as recent changes of defence policy have so often had the incidental effect that Britain has to turn to weapons of a kind only in development or production abroad. If actual weapons are not forthcoming a national effort should be made in producing hardware associated with new materials and methods of fabrication; design studies in themselves are not sufficient. We could also attempt to improve technical communications in locating scientific information and translating it into useable design data which could be applied equally to missiles and aircraft. This paper has not been an easy one to write, but within the limits of information that can be published, an attempt has been made to show that the early structural philosophy of British missiles was an improvement on German thinking. Many methods of construction shown have evolved from aircraft practice and the future seems to point to the fact that aircraft and missile interests will be even more common.

The art of missile design is an extremely difficult one, since whatever may be achieved there is always a consciousness that it ought to be done more cheaply. However, the importance of structural weight, aerodynamic environment, storage life and reliability are incompatible with the term "cheapness" in the sense of "crudeness."

The Fourteenth Lecture to be given before the Astronautics and Guided Flight Section—on 7th February 1961.

NOTATION

ρ	density (lb./in.²)
p	internal pressure (lb./in.²)
E	Young's modulus (lb./in.²)
R	radius of cylinder (in.)
t	thickness of cylinder wall (in.)
δ	maximum inward initial irregularity (in.)
f_b	critical compressive stress (lb./in.²)
K	buckling stress coefficient defined by $f_b = KE(t/R)$
l	length of cylinder (in.)
F	axial compressive load (lb.)
P_H	maximum hydrostatic pressure (lb./in.²)
f_a	allowable tensile stress (lb./in.²)
σ_{hy}	= hoop yield stress (lb./in.²).

Explanation of parameter $\frac{pR}{Et} / 0{\cdot}007$ used in Fig. 19:—

for conventional materials, the tensile yield strain

$$(\sigma_{hy/E}) + 0{\cdot}002 \simeq 0{\cdot}007.$$

Therefore this value has been used for σ_{hy} in preparing the curves.

2. Background

In Britain, the manned aircraft has had over 50 years of development including the impetus of two world wars; our missiles, on the other hand, have only been developed since 1945. The structural problems associated with early missiles were less complex than contemporary aircraft and consequently the feeling has grown that missile structures are simple and require no elaborate analysis. One well known "textbook" issued by the Air Ministry dismisses missile structures in a few lines. The airframe is simply defined as that "which connects and encloses the warhead, guidance, control, propulsion and power supplies. It includes wings where lateral control forces are produced aerodynamically." While there is no wish to cavil with this as a definition, one feels that missile structures are often taken for granted.

As a comparison, often a doubtful one, aircraft structures are quoted as having a high degree of sophistication. What aircraft do have is a high degree of reliability and structural integrity brought about in large measure by the presence of the human pilot. A pilot monitors the behaviour of the aircraft and can compensate for any non-catastrophic malfunction and bring the aeroplane back, so that exhaustive analysis of faults can be made. Guided missiles on the other hand lack judgment and have no instinct of self preservation. If partial failure occurs it almost invariably means failure of the whole, because no elaborate preventive action can take place. Furthermore, the analysis of the defect is difficult even with highly instrumented test vehicles, and virtually impossible with operational missiles.

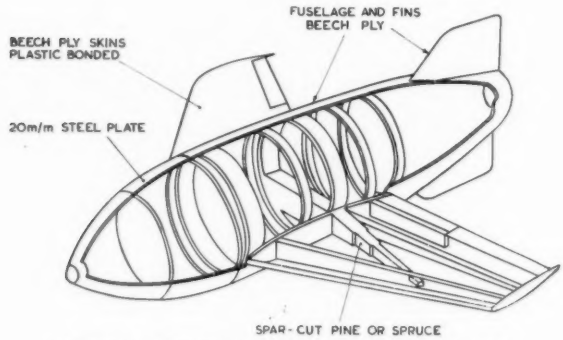


FIGURE 1. Enzian, November 1944—January 1945.

This aspect of the problem is borne out by the number of prototypes or rounds. Two or three aircraft can and do produce most flight test data, while tens or hundreds of missiles are required. Emphasis is given to this point from German experience, where "it is estimated that about 3,000 A4s (*i.e.* the V.2) were used for experimental testing and training purposes. It is thought that about one-fourth of the total number used proved to be failures owing to errors on the part of the launching troops or to structural defects."(1) This figure is enormous by our standards.

While few British missiles which have been open to public inspection can be said to possess structural refinements, it is also true to say that they have had a minimum programme of flight testing. What has obviously happened is that the structural designer has had to freeze his design early in the development stage having once proved it to be satisfactory. However, if missiles are to carry atomic warheads, then refinement and integrity of design, at an increased cost, are fully justified on the grounds of absolute reliability.

3. Constructional Trends

If one examines German missiles it is apparent that they were designed for the greatest possible ease of construction. Each of the component parts was of the simplest form, even at the expense of additional weight. Post-war missiles on the other hand are consistent in the use of aircraft materials and constructional methods, and the uninformed are tempted to ask if this practice is justified in a one shot vehicle. Missile firms have given this matter a great deal of thought and it is unfortunate that many of the excellent reports in the archives of our missile constructors cannot be reviewed. It is probably true to say that the more progressive missile designers have made a closer study of structural costs than aircraft designers. The difficulty with analysing missile costs is to choose the correct criterion. Is it lethality, reliability or performance? It is not proposed to answer this question but let us consider a comparison of a late German weapon and an early British weapon of nearly comparable roles.

Figure 1 shows the German Enzian missile which had a range of over 20,000 yards, weight 4,350 lb. with four solid rocket boosts and a speed of $M=0{\cdot}9$. The nose is 20 mm. (0·8 in.) mild steel plate. The centre section is plastic wood (Formholz) consisting of several layers of beech veneer pressed and glued with Tegofilm. The wing is of similar construction with the main spar made of cut pine or spruce. The tail cone and fin are also of wood. A British missile, Fig. 2, is approximately the same weight and has four solid rocket boosts, but it has far better performance and is made mainly of light alloy conforming to aircraft practice. Development of the Enzian was stopped in March 1945 and it was never proved, although plans were being pushed ahead to design a supersonic version. German technicians considered the $M=2$ version "had little chance of success because a wooden projectile—particularly the wing system—is too heavy and cannot be constructed to the degree of accuracy demanded by supersonic aerodynamics."(1)

Figure 3 illustrates the effect of the choice of material and forms of construction when two pairs of wings are added to a given hypothetical missile body capable of a speed $M=2$. The addition of the wings increases the weight and the drag, both of which have an adverse effect on the range. We will make the simplifying assumptions that the wing has a given plan form and has a load-carrying structure of rectangular section with a constant chord tapering uniformly from a root thickness T to a given section at the tip. The weight of the wing can then be expressed as a function of the density of the material and the thickness. But the thickness required is related to the tensile strength of the material in order to carry a given load. Similarly the drag, which depends on the thickness, is also related to the tensile strength. Hence the loss of range resulting from the combined effect of both is then a function of the tensile strength and density, which depend on the choice of material. The

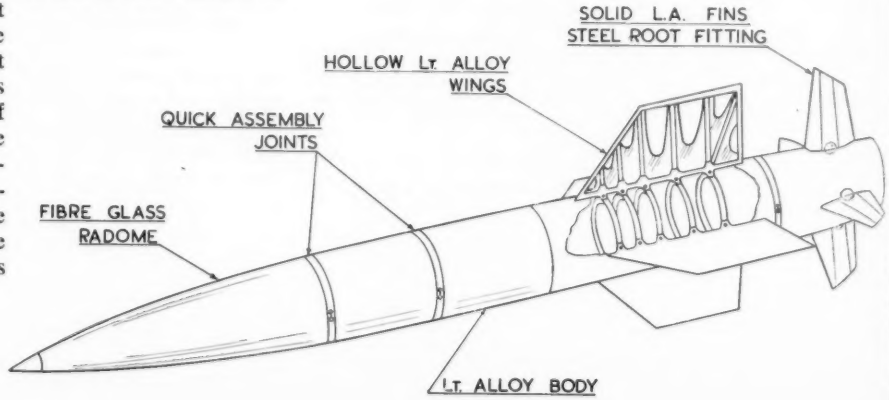


FIGURE 2. Simplified structure of British missile.

hollow construction has the effect of lowering the effective density and the effective strength. Therefore, for a given material, we have a point on the graph representing the solid construction. From this point, we can draw two boundary curves to envelope all possible hollow sections. The lower boundary represents the most efficient arrangement and the upper boundary the most ineffective arrangement of the available material. A point representing a 50 per cent hollowness and 73·4 per cent equivalent strength is shown to give an example of a realistic arrangement.

It appears in this particular study that a hollow high tensile steel wing gives the best performance and hollow light alloy wing the worst, while wood having too low a strength, cannot be plotted on this scale. It is also interesting to find that a very high tensile, solid and therefore simply constructed wing is preferable to the low tensile, hollow, light and sophisticated but high drag combination.

The effect of wing stiffness has been neglected in this particular study, as also has the drag due to lift, and the plan form of the wing has been kept constant, consequently this simplified approach should be treated with caution. Nevertheless we know that as missile speeds and skin temperatures increase the light alloys will be superseded by steels for primary structures. There is a performance advantage in fabricating a heavily loaded wing from high tensile steel and as the construction is likely to be a shell structure, the design philosophy will be anything but "cheap and nasty" and considerable ingenuity will be needed to keep structural costs reasonable.

3.1. MANUFACTURING TECHNIQUES

The use of high strength materials has already necessitated the development of novel manufacturing techniques. One of them is a process for the controlled removal of metal from defined areas of a component by chemical attack, known variously as chemical milling, contour etching and chemical contouring. This process is not a substitute for machining irrespective of design, and should be specified only when machining is impossible or too costly. Chemical contouring is applicable to aluminium, magnesium, titanium and steels. Steels being used less widely than light alloys in the Aircraft Industry, have consequently received less attention. Langstone, Hoyle and Adams[2] describe the techniques developed by Bristol Aerojet Ltd. for the chemical contouring of one per cent chromium molybdenum steel, hardened and tempered to a tensile strength of 80 tons/in.^{2}. However, attention will need to be paid to the use of ultra high strength steels for chemical contouring compatibility. A profitable use of this process, outside the more common applications such as waffle patterns, integral constructions and double curvature pressings, may be applied to welding. When a steel is welded there is a reduction in both the fatigue limit and endurance at high stress levels. Effective thickening of the material at the weld by chemically contouring all surfaces except in the region of the weld could lead to an optimum strength/weight ratio.

If we now turn to machining, the work currently in progress in the Production Department of the College of Aeronautics is of interest. Fig. 4 shows an oblique angle face mill, designed primarily for machining high tensile steels. The cutters are tungsten carbide and are circular in form, which enables them to be rotated, thus bringing new cutting edges into position. This operation can be repeated approximately forty times before the discs need regrinding. Test results so far obtained in machining 120 T steel in the fully heat treated condition are very encouraging. With a feed of 3 in. per minute and 0·05 in. depth of cut, the time between regrinding the cutters is 90 minutes, about treble the life of a normal cutter.

Mild steel and non-ferrous

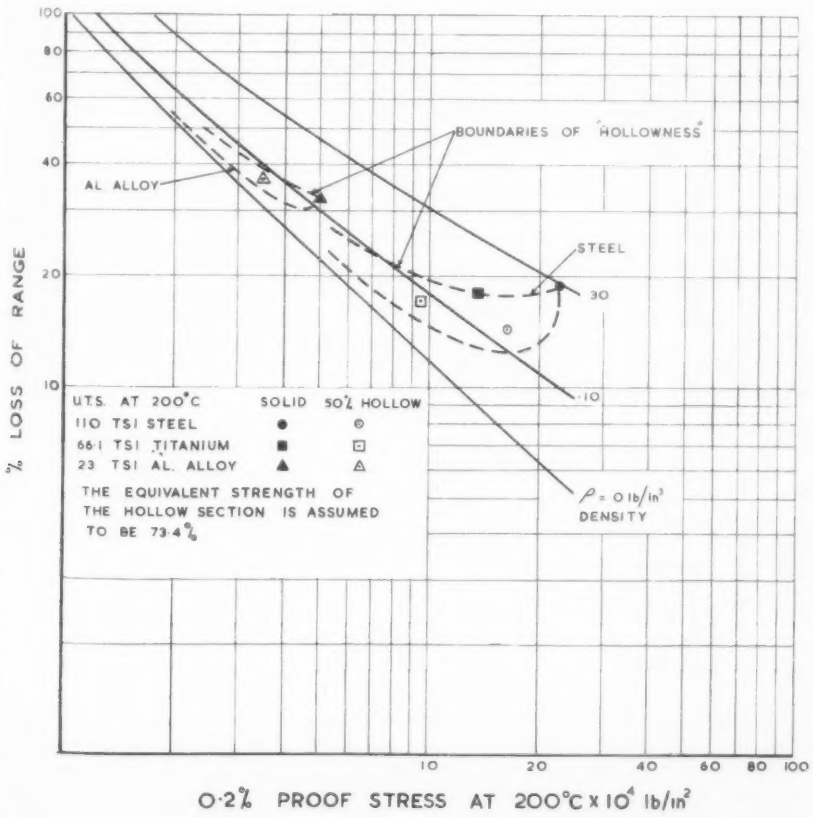


FIGURE 3. Effect of wing material on range.

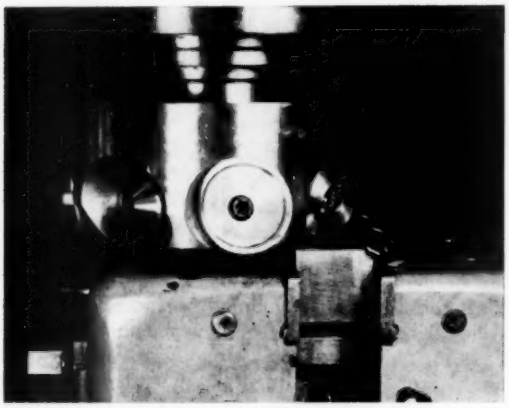


FIGURE 4. Oblique angled milling cutter.

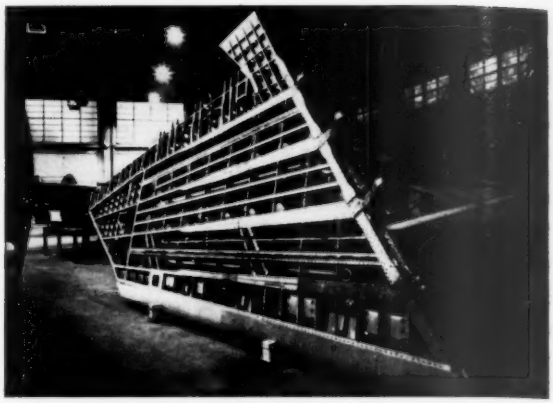


FIGURE 5. Hawker P.1121 wing.

metals can be satisfactorily machined with this tool and feeds up to 84 in. per minute have been obtained on mild steel.

Although comments on chemical contouring and machining of high tensile steels may seem out of place at this stage, steel wings and shells for missiles are already in being, and these two techniques are typical of methods which can and will be developed further with a consequent reduction in fabrication costs.

4. Comparison of Aircraft and Missile

The wing of the P.V. Hawker P.1121, Fig. 5, has a multispar construction and light alloy skins which are 0·3 in. at the root; the inboard 5 ft. of the spars are machined from H.T.S. forgings. The general impression of the structure is that it is typical of what is expected in a Mach 2 aircraft wing.

The wing of the missile, Fig. 6, shows the same principle of multi-spars. Doubling plates are used instead of tapering the skins and the root rib is a machined forging. The material is light alloy throughout and methods of construction are similar but in miniature.

Now machined integral skins have long been used on aircraft and Fig. 7 shows the main wing skin plank of the North American F.100. There are approximately fifty separate conditions that design the wing skin, such as normal flight, inverted flight, underwing stores and so on. Each condition may be critical in a different area and the resulting contour map of required skin thickness precludes the use of straight tapers. The material is high grade light alloy and is stressed as high as 65,000 lb./in.^{2}

If we now refer to Fig. 8 we see an integrally machined wing for a modern missile, only here the material is high tensile steel, something as yet not attempted for a whole aircraft wing. Fig. 9 shows a boost fin of a missile machined from a solid light alloy slab and this compares with the Hawker P.1121 tailplane (Fig. 10) machined from similar material.

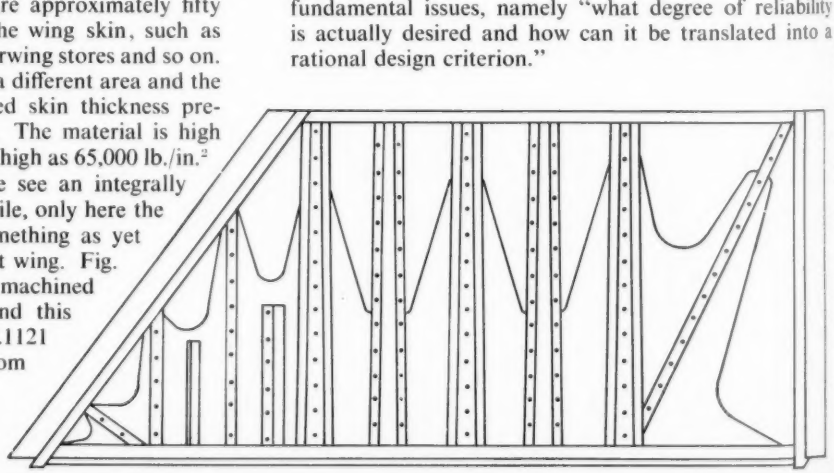


FIGURE 6. Missile wing (light alloy).

These examples illustrate that, size for size, the missile is becoming as complex as the aircraft, even though the missile is designed for a very short working life. It is the greater size and the addition of trailing edge flaps and ailerons, together with the fact that fuel is carried in the wings which makes the aeroplane more complex, but one is hard pressed to differentiate between a Mach 2 aircraft slab tailplane and a high Mach number missile wing.

5. Safety Factors

One of the controversial topics associated with missiles of all kinds is the philosophy of safety factors.

For some small missiles weight may be secondary to economics and an arbitrary safety factor is desirable. Farrar[3] (1959) discussing the Bloodhound missile considers the evolution of the design based on "initial weaknesses" to an approved final stage as a satisfactory method. With large missiles a small change in the factor of safety can mean a significant change in structure weight and the evolution method would be too expensive. Anderson[4] (1959) and Dow[5] (1960) are of the opinion that in view of strong pressures to reduce factors of safety, it is necessary to examine the more fundamental issues, namely "what degree of reliability is actually desired and how can it be translated into a rational design criterion."

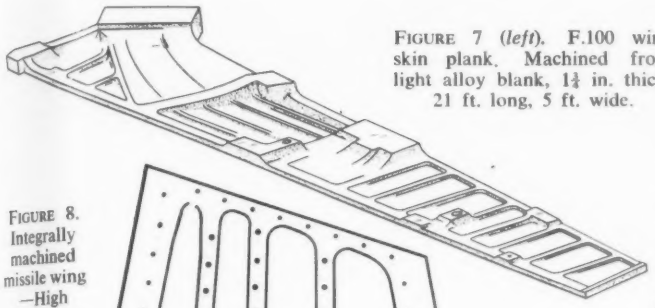


FIGURE 7 (*left*). F.100 wing skin plank. Machined from light alloy blank, 1¾ in. thick, 21 ft. long, 5 ft. wide.

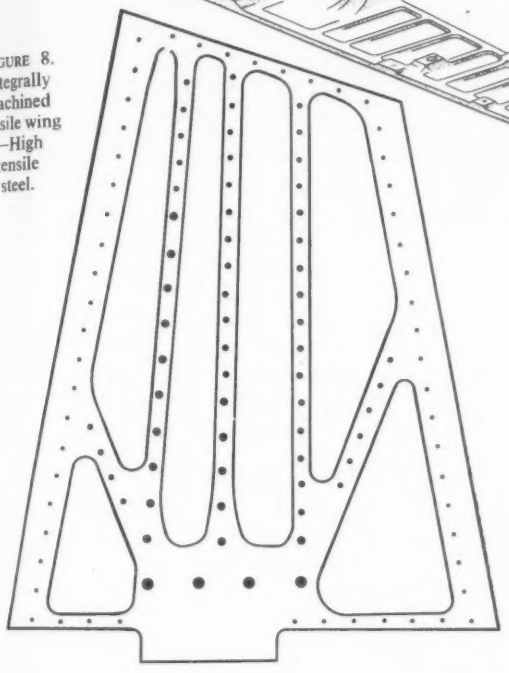


FIGURE 8. Integrally machined missile wing —High tensile steel.

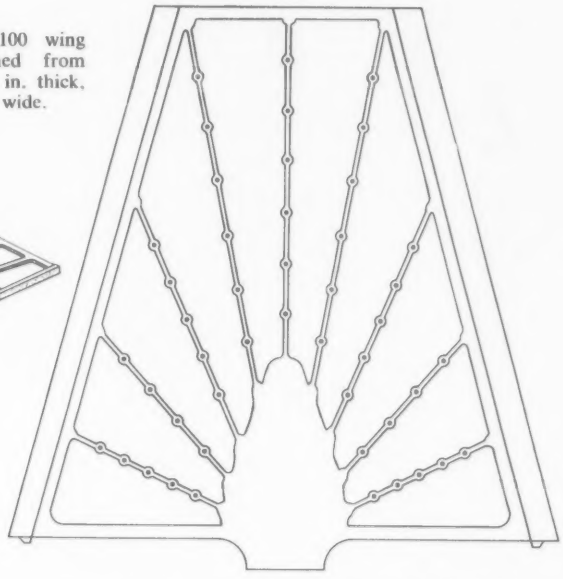


FIGURE 9. Integrally machined boost fin—light alloy.

In missile design "safety," except to personnel at pre-launch and launch, has very little significance and perhaps the determining factor should be reliability. However, reliability or acceptable probability of loss may be arrived at in many ways, and when high structural efficiency is required, ignorance factors should be kept to a minimum. Design criteria for British missiles have a security classification but it is understood that structural strength in flight has to meet a proof factor of $1\frac{1}{8}$ and an ultimate factor of $1\frac{1}{3}$, and to guard against the launch phase failure a proof of $1\frac{1}{4}$ and an ultimate of $1\frac{1}{2}$ with all boost motors working. American data[6] on the other hand quotes factors of safety for free flight loading conditions of 1·0 for limit loads and 1·25 for ultimate loads, and 1·5 for handling and captive flight conditions. With an aeroplane, extra weight detracts somewhat from performance, but the 1·5 safety factor has come to be accepted almost as one of the facts of life. Such an arbitrary number can be justified on a number of grounds, but perhaps the primary one was that it expressed the ratio of ultimate to yield stresses of materials commonly used in aircraft when the criterion was first established. This enabled the designer to use yield stress for limit loads and ultimate stress for ultimate failure loads. A factor of safety has no significance as a measure of yield to ultimate stresses when applied to instability failures. The shape of the stress/strain curve determines the instability failure: whereas the yield and ultimate stresses define tensile failure. Some of the materials now in use have ultimate-to-yield stress ratios of 1·1 to 1·3. Thus the 1·5 safety factor has become an arbitrary number, which can be defended on the grounds that it provides a comforting margin of safety when transporting human lives.

Not that there is much comfort in the use of a 1·5 safety factor guaranteeing absolute safety if load determination and stress analysis is in error. Ref. 4 cites the results of a survey where 57 per cent of aeroplane wings tested failed below ultimate load and 13 per cent failed less than limit load.

However, in missiles where structure may be the next largest weight item to fuel, an arbitrary safety factor seems illogical. If the data given for British and American factors is correct, then for free flight loading conditions our figures are 12·5 per cent more under proof conditions and 8 per cent at ultimate.

It would be interesting to have the opinions of the British missile designers to see if they agree with the American viewpoint that factors should be reduced. If they do, then perhaps the first step would be to make British and American factors identical.

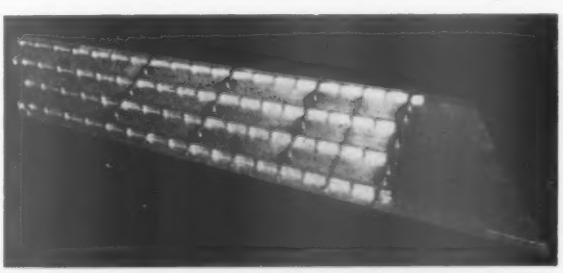


FIGURE 10. Hawker P.1121 tailplane.

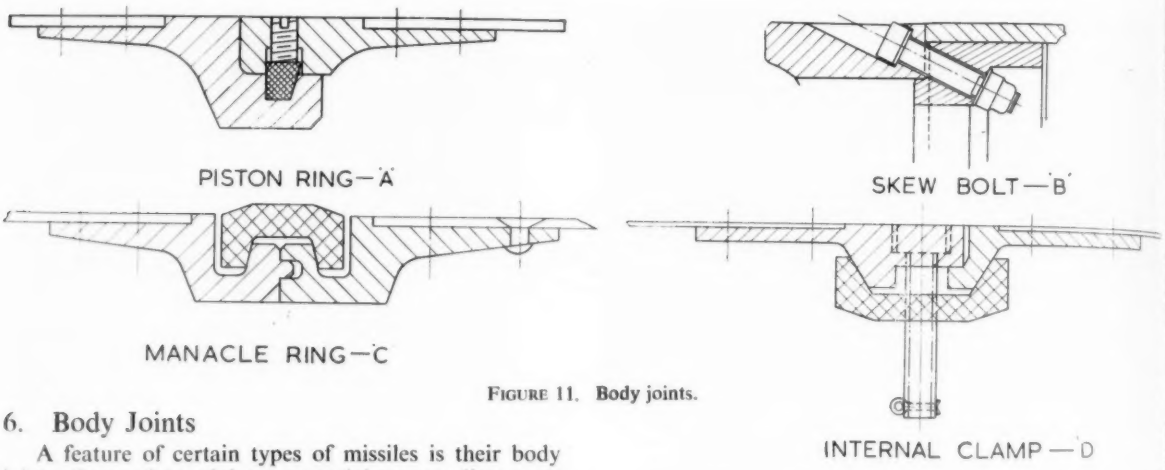


FIGURE 11. Body joints.

6. Body Joints

A feature of certain types of missiles is their body joints. Some of these joints are special connect-disconnect types, needed for field maintenance or assembly, installation of a warhead, rocket motor or similar requirements.

Joint design can affect the structure aeroelastically, both from a stiffness and damping aspect. It is important to meet the requirements of these régimes with as small a scatter as possible, and though joints are a matter of detail design their analysis can be complex.

Four types of joints are shown in Fig. 11.

Type A. This is an ingenious joint used on a missile 12·5 in. diameter. The joint is made by a split spring steel piston ring held in position by a number of Allen-type screws. This joint was embodied in a missile where four joints along the body contributed only 20 per cent of the body deflections, the remainder being made up of bending and shear deflections of the body skin.

Type B is a skew bolt joint, and this type appears on torpedoes as well as missiles. As a number of bolts make a connection it could be considered to be dissimilar from the other types in so far that it is not quick release. It has proved to be very satisfactory and on one occasion when the skew bolt was changed for a different bolted joint, the fundamental bending frequency of the missile body was lowered to a sufficient degree as to cause an instability of the auto-pilot loop. It is a type of joint finding favour on some of the latest projects, although it featured on one of the earliest British missiles.

Type C is a manacle ring joint. The clamping ring is articulated and correct tension is obtained by snapping over a toggle and then applying torque to a turnbuckle. Body bending moments on a diameter of approximately 21 in. are transmitted across this joint, and with all these types of joints, forces occasioned by longitudinal, lateral and pitch accelerations have to be withstood.

Type D is an internal clamp which gives a smooth exterior finish. The clamp consists of a number of arc-shaped machined fittings and is similar to one which is in use today.

There are other methods of making body joints, other than these, which have been given as a representative selection. Naturally they are accurately made because body alignment is most important. Structurally they are an embarrassment because the frame weight can be a weight penalty. Designers however take advantage of the need for the heavy frames by positioning them to react the loads occasioned by boost and sustainer motors, handling and launching attachments. They are also used for supporting internal equipment.

7. Honeycomb Construction

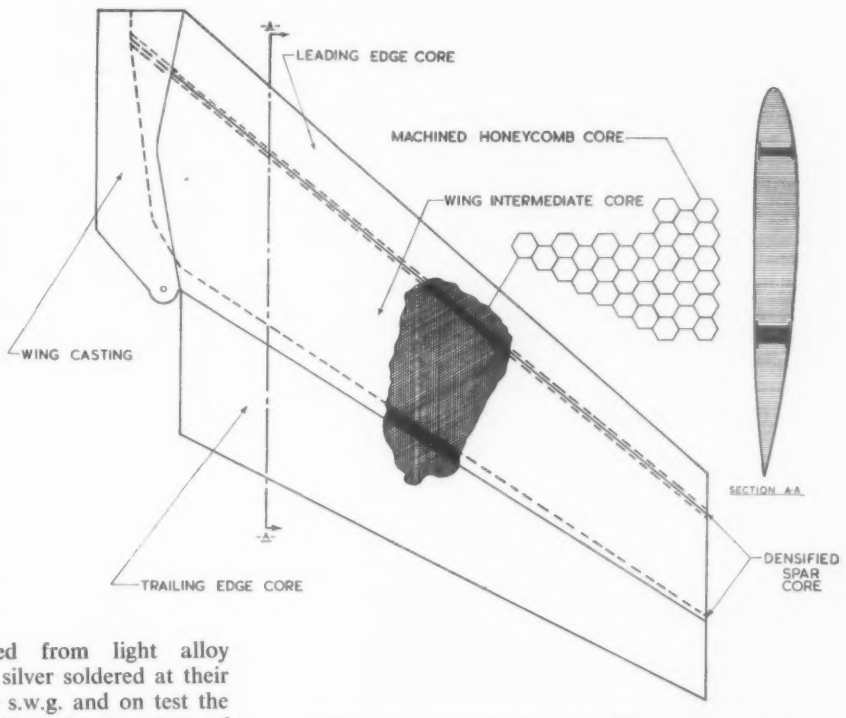
Aircraft structural engineers have long been intrigued by the possibility of eliminating the thousands of assembly operations involved in a typical "bits and pieces" airframe structure, and the use of integrally sculptured skins has illustrated this trend. However, one of the obvious solutions was the use of low density honeycomb cores, with skins bonded to the core.

The B-61A Matador wing (Fig. 12) was the first production missile using honeycomb construction. As can be seen the number of major parts are few and the most interesting feature is the use of fully compressed cores for the spar webs.

Holback and Burridge[7] (1954), give an account of the experience and background knowledge which made the use of adhesive possible in the Matador and it is a classical example of the interchange of information between missiles and aircraft going on within a single company. The Gorgon IV, a pilotless aircraft used the first flight surface of sandwich construction and, although approximately 80 wings were manufactured, no metal-to-metal bonding was involved. The Martin 202 and 404 aircraft used structural honeycomb floors of flat sandwich panels and the development work on these floors allowed sandwich type surfaces to be used on an experimental version of the Matador. The production version of the Gorgon IV known as the KDM-1 came into being at this stage and embodied the first major use of metal-to-metal bonding.

These applications, all involving production in some volume, paved the way for the B-61A. Their effort took some years to achieve (Fig. 13)[7] and it was found in the engineering phase that wings or aerodynamic surfaces made with honeycomb filling the entire internal volume of the aerofoil are economical, weight-wise for areas less than 200 square ft. and thicknesses-chord ratios of 10 per cent or less.

FIGURE 12. B 61-A Matador wing.



An interesting British example of honeycomb construction as applied to missiles was produced around 1954. The requirements of the wing were high strength and stiffness (particularly panel stiffness) minimum thickness and weight: good surface finish and ease of production. The ultimate design load on a panel area of 4·5 square ft. had to be resisted by a wing only 1·25 in. thick at its deepest section.

From Fig. 14 it can be seen that the wing has only two shear webs, located at the bend line of the wing skin, and the honeycomb is only partially expanded to increase the spanwise shear area of the core. The root and edge members were machined from light alloy extrusions, argon arc welded or silver soldered at their junctions. The skins were of 20 s.w.g. and on test the wing failed by breaking the tension skin at a stress of approximately 50,000 lb./in.^{2}. Consequently it may be assumed that the compression skin was working up to an equivalent stress without buckling and this gives some indication of the degree of support given by a honeycomb core in this type of construction.

This wing was developed before the days of high temperature adhesives, and Redux bonding was used. As the strength of Redux falls rapidly at 100°C the wing was lagged against aerodynamic heating effects. A layer of Durestos cured down to $\frac{1}{64}$ in. thick protected the core to skin bond against premature shear failure. The weight of the wing is approximately 4·5 lb./ft.^{2} and there is little doubt that this wing could have been developed further using high temperature adhesives thus saving the weight of the lagging.

The wing of the Raytheon Hawk is of similar construction to the one previously mentioned, although it is believed that the honeycomb core is uniform and does not have the feature of the partially expanded core. The wing is bigger, having approximately 7 ft. chord at the root compared with nearly 4 ft. The skins are made from 7075 T6 material 0·051 in. thick and are preformed. The supporting honeycomb foil is 0·003 in. and each wing contains only 3 rivets. It is estimated that a complete set of Hawk wings can be produced in 22 hours.[8]

With supersonic vehicles necessitating a change from aluminium alloy to steel skins, due to kinetic heating effects, research efforts have been directed towards the development of high temperature resistant bonded structures.

Techniques have been successfully developed for bonding stainless steels and other alloys with organic adhesives which have adequate strength for use below 250°C. This, however, is below the thermal capabilities of stainless steel. Satisfactory silver brazing techniques have been developed in the production of steel honeycomb construction in a long-time temperature environment of 400–450°C, but brazing is a costly operation. A need has arisen for a low production cost adhesive system capable of use with steel to operate around 400°C.

The U.S. Navy Bureau have under development at the present time a programme for a ceramic bonded stainless steel structural component using steel honeycomb, capable of long service life at temperatures up to 800°F (426°C). Already a ceramic-braze adhesive has been

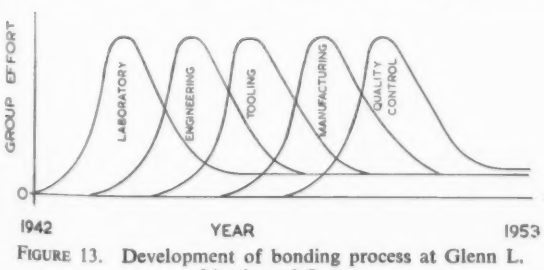


FIGURE 13. Development of bonding process at Glenn L. Martin and Co.

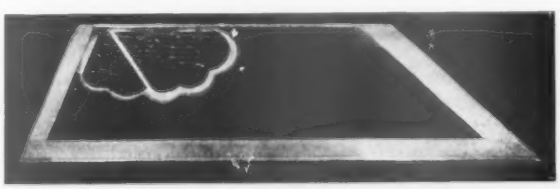


FIGURE 14. British honeycomb wing.

developed and preliminary results[9] show that a major advance in the art of low cost bonding has been achieved. From a processing point of view the ceramic-braze adhesive offers the following advantages over standard brazing techniques: the metal surface preparation is simple, the machining tolerances are less critical and the tooling employed is cheaper. The bonds obtained are primarily metallic and possess the desirable mechanical characteristics of the joined metal members. The minimum acceptable tensile lap shear strength has been specified as 6,000 lb./in.^{2} at room temperature; tests greatly exceed this figure, and at 426°C results show values in excess of 4,500 lb./in.^{2}. Since this process is in the nature of a progress report and as such is tentative and subject to changes, it is nevertheless indicative of the type of work referred to in the introduction that we should be engaged on in this country.

8. Thin Shells

With the present emphasis in the U.S.A. and U.S.S.R. on space vehicles, thin shell design is bound to become increasingly important, especially minimum weight design. Gerard[10] has already drawn attention to the fact that the airframe/gross weight ratio has shrunk from 0·35 to 0·2 for manned aircraft, ballistic missiles from 0·05 to 0·02; space craft from 0·10 to 0·02.

Gerard also points out a significant trend in the way airframe weight subdivides into tension, compression and shear criteria; he states "approximately one third of the airframe structural weight of an aircraft or aerodynamic missile is governed by tension considerations and two thirds depend on compression and shear buckling." This is one of those generalisations which may apply to so-called optimum structures, but rarely to operational vehicles. It is probably more correct to say that almost half the structure weight of aircraft and aerodynamic missiles is taken up by essential engineering requirements demanded by servicing, maintenance and handling which results in joints, access panels and general structural discontinuities, the remaining structure may subdivide as Gerard suggests.

In ballistic missiles with their greater use of pressure vessel type structure, half the weight may be governed by tension and half by buckling. Space craft can make an even greater use of pressurised shells and two thirds of their weight could be governed by tension considerations.

This means that approximately 80 per cent of the total weight of a ballistic missile and 90 per cent of the weight of space craft will be distributed in the form of thin sheet products.

The first ballistic missile relying on internal pressure for structural integrity was the MX-774, Fig. 15. K. J. Bossart of Convair Astronautics was responsible for its design, and although he hesitates to claim he originated the concept, he admits it took courage to put the idea into practice for the first time.[11] Actually the MX-774 only needed the strength contributed by pressure to resist flight loads. On the ground the missile would stand erect without pressure even when fully loaded. This, of course, is not so for the Atlas where the pressure concept is utilised to its fullest extent.

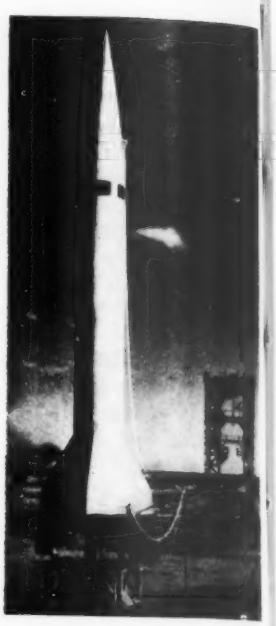


FIGURE 15. MX-774. The first ballistic missile relying on internal pressure for structural integrity.

In Fig. 16, the completed 60 ft. Atlas shell is being moved by cranes. All the supports have been removed from the thin-skinned tank and it has been pressurised to enable it to hold its shape. By contrast those missiles in course of construction have heavily wrinkled skins, Fig. 17. Another innovation first demonstrated in the MX-774 and now used in the Atlas as well as several other missiles, was the use of integral tanks to contain a cryogenic propellant. For the first time no thermal insulation was provided between the missile shell and the liquid oxygen.

Structural refinement of large thin shells brings many problems, weight saving cannot be done without some loss of rigidity. If bending frequencies are allowed to fall they may approach the servo frequency of the missile in which case the gyros cannot distinguish between the missile attitude changes and bending deformation. This phenomena is also true of aerodynamic missiles. There are also problems associated with fuel sloshing, eccentricities and stress concentrations but a review of these is too involved for a paper of this sort.

9. Combined Compression and Internal Pressure

As has been stated this condition is important in missile design. The thin-walled cylinder used for the missile structure will buckle under compression, and it is

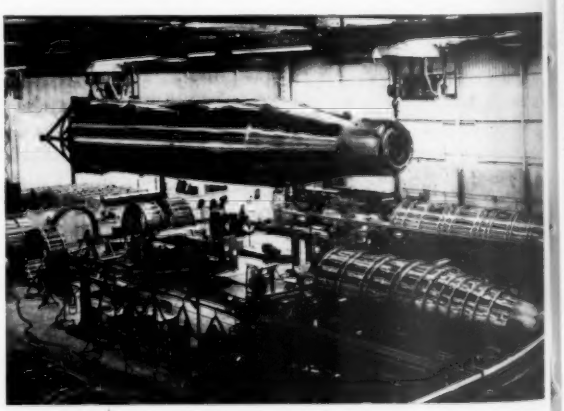


FIGURE 16. Completed 60 ft. Atlas shell being moved by cranes.

interesting to see what happens to the buckling stress as we increase the internal pressure. It is believed the designers in this country generally rely on the information given in the R.Ae.S. Data Sheet 04.01.01, (Fig. 18) where the buckling stress coefficient k is plotted for various values of the pressure parameter $(p/E)\ (R/t)^2$ against the initial eccentricity parameter δ/t. Great importance is attached to the effect of the initial irregularity δ, since it is the cause of the drop in buckling stress for the unpressurised compression cylinder. (*See* curve with $(p/E)\ (R/t)^2 = 0$.) The internal pressure is thought to smooth out these initial irregularities. Therefore if one could build a perfectly smooth and regular cylinder the effect of the pressure would be nil, and the buckling stress would have the theoretical value of $0{\cdot}605E\ (t/R)$. The same data sheet gives also the effective ratio of δ/t plotted against R/t, since it is always difficult to interpret the actual measurements of irregularities. This figure is based on experimental results, and the effective values of δ/t are obtained by working back from the top figure. By using these two figures, the buckling stress is actually estimated on a statistical basis.

In America however, the information as summarised by Klein[12] (1960) shows a distinct difference. He maintains that as the pressure is increased, there is a sharp rise in buckling stress at first. Then after some values of pressure are reached, the buckling stress remains constant for a while and actually drops as the pressure is further increased. He attributes this fall to the bulging of the cylinder and later yielding in the hoop direction. Although he acknowledges the effect of imperfections, no allowance is made for it, and the buckling stress coefficient k is plotted for different values of the length parameter L/R, which is deemed to be more important. He also objects to the use of the parameter

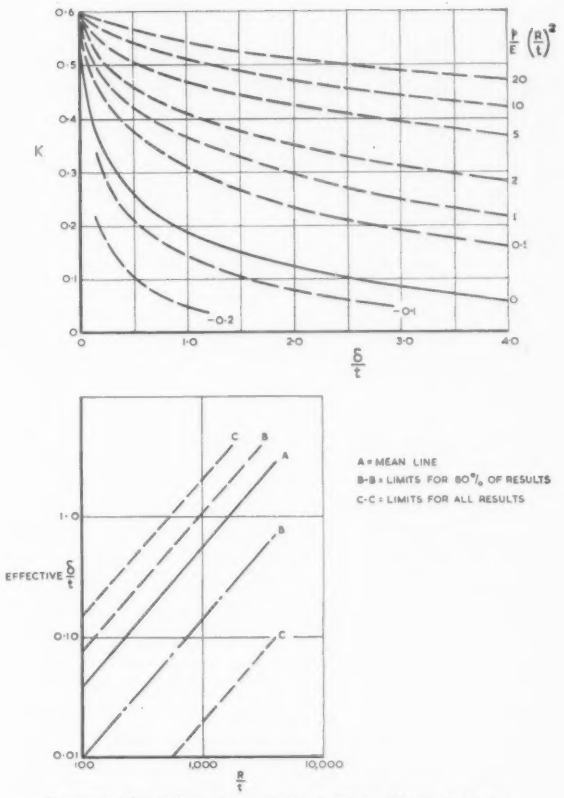


FIGURE 18. Taken from R.Ae.S. Data Sheet 04.01.01.

$(p/E)\ (R/t)^2$ on the grounds that it is indifferent to thick cylinders with high hoop stress and thin cylinders with low hoop stress, and used instead the parameter $(p/E)\ (R/t)/0{\cdot}007$, which is the ratio of the hoop strain to the yield strain.

The amount of disagreement between the two methods can be seen by replotting the R.Ae.S. Data Sheet on the American scale and the case of $R/t = 2500$ as shown in

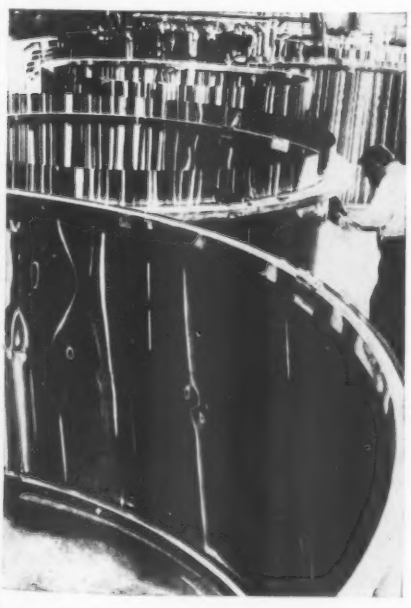


FIGURE 17. Sections of Atlas shell under construction.

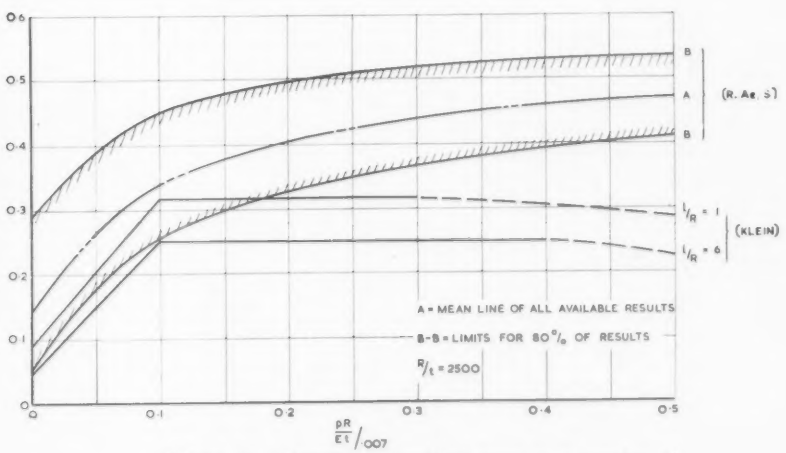


FIGURE 19. Compressive buckling stress as a function of pressure hoop strain.

Fig. 19. The difference can be seen to be as much as 100 per cent in places.

However, it is not intended to pass an opinion as to which criterion should be used in designing pressurised thin shells. In the case of practical structures either or neither approach may be the correct one. It is sufficient to point out that in spite of a vast amount of theoretical and experimental work throughout the world, the accurate prediction of thin shell behaviour may not be so simple after all.

The original intention in writing this section was to emphasise the importance of a sound manufacturing technique. The R.Ae.S. data certainly shows that if irregularities are kept to a minimum a higher buckling stress can be used with a consequent saving in structure weight.

10. Manufacturing Problems of Large Thin Shells

The problem of constructing monococque shells from high strength stainless steel to have absolute structural integrity under pressure is not easy. In the Blue Streak structure, the basic method of joining the sheets to form the shell is fusion butt welding with no filler wire added to the weld. The two abutting edges have to be positioned and held to a high degree of accuracy, *i.e.* the gap must not be less than 0·003 in. or more than 0·010 in. The backing bar and clamping device are part of a rigid fixture along which moves a trolley carrying the welding head (Fig. 20). The sheets to be joined are clamped by a series of independently hinged L-shaped fingers, which are pneumatically operated. The gap between the clamping edges is kept as small as possible—from $\frac{1}{4}$ to $\frac{1}{2}$ in. depending upon the size of the shrouding nozzle. The combination of heavy backing bar and closely spaced fingers provides a very good heat sink, and thus minimises the extent and temperature of the heat affected zone during welding. The backing bar is $2\frac{1}{2}$ in. wide, 2 in. deep with a groove $\frac{1}{16}$ in. deep by $\frac{1}{4}$ in. wide along which argon/helium mixture is fed to protect the underside of the weld.

Careful control of the welds is also required if the strength of the structure is to be maintained and distortion kept to a minimum. Stainless steel, type F.S.M.1 cold rolled to 85 tons/in.^{2} is used and joint efficiencies of 70 per cent are common.

In the Atlas missile the sheet material is SS Type 301, a work hardening steel which is not heat treatable. Some of the sheet thicknesses are 0·01 ± 0·0005 in., consequently the stretch forming of such thin material is an extremely difficult operation, particularly on curved bulkheads. The complete shell is made up of a series of sections, approximately 5 ft. long, each section comprises two basic rings, mated by lap welds. No details have been published as to how these joints are made but considerable ingenuity must have been exercised to make them fuel-and pressure-tight.

Another method of making long thin-walled tubular components has been used by Bristol Aerojet for many years. Sheets of material of thicknesses ranging from 0·036 to 0·104 in. rolled into cylindrical form can be loaded into the welding jig. Clamping fingers, the faces of which are covered with heat insulating material, hold the edges of the rolled tube in contact with a backing bar which is supported along its length by means of a beam (Fig. 21). A welding head incorporating electronic arc length control mounted on a motor driven tractor, is used to weld the seam and filler wire is added automatically as the welding proceeds. The argon-arc welding of the one per cent chromium 0·25 per cent molybdenum type steels have already been described by Wilkinson and Cottrell[13, 14]. Their work shows that with careful choice of steel composition and heat treatment the strength of the welds can be made equal to that of the parent metal. Internal pressure is applied after welding to make the cylinders truly circular.

FIGURE 20. Welding fixture and equipment used for joining the gores to form tank diaphragms—de Havilland.

FIGURE 21. Welding fixture for solid rocket body—Bristol Aerojet.

The first stage of Minuteman, 65 in. diameter by 20 ft. long is probably a heat treatable steel, specification D.6A one per cent Chromium. The case consists of several cylindrical sections machined from rings and welded together in special fixtures. Test specimens 2 ft. diameter by 3 ft. long made by the Allison Division of General Motors Corporation were made from forgings and machined down to 0·08 in. thick. The uniaxial tensile stress of the material is 125 tons/in.^{2}, 0·2 per cent yield is 107 tons/in.^{2} with 5·6 per cent elongation. This gives a yield strength/density ratio of approximately 860,000 in. Efforts are being made on some U.S. missiles by change of material and construction to increase this ratio to over 1,000,000 in.

Now missiles such as Minuteman, which uses a solid propellant bonded and cured to the case, have interested many theoretical and experimental workers in the visco-elasticity field. Goree and Nash[15] have investigated the effect of a soft elastic core upon the buckling strength of a thin circular cylinder. The core has a strengthening effect which becomes more significant with the increasing values of the radius/thickness ratio. The results show that for the geometric and elastic constant considered it is possible to increase the buckling stress by as much as 65 per cent over the values of those without an elastic core.

Obviously much more work will be undertaken in this field, but if the technique becomes established in the interests of weight saving, then truly the success of the structure will rely on a perfect bond with core and manufacturing techniques become more important.

11. Ballistic Missiles. Structural Design

In this section it is intended to deal very briefly with the effect of axial loading on a hypothetical ballistic missile and to discuss the pressure concept if used to the fullest extent, *i.e.* no mechanical stabilisation.

The main cases which govern the design of a ballistic missile structure include:—

(*a*) Axial compressive loads due to thrust of the motor and the reaction of inertia and drag forces.
(*b*) Shear forces and bending moments due to winds, gusts and manoeuvres.
(*c*) Pressure in the tanks:—
  (*i*) due to hydrostatic head of liquid.
  (*ii*) due to gas pressure above the fuel.
(*d*) Liquid sloshing loads.
(*e*) Thermal stresses.
(*f*) Panel flutter.

If the missile of Fig. 22 is assumed to weigh 300,000 lb. of which 90 per cent consists of fuel and oxidant, then making suitable assumptions for the in-flight motion of the missile and data from Ref. 16, it can be shown that for Tank *A* the most critical axial loading case occurs at burnout, and the hoop stress in the skin is less than for Tank *B* which undergoes its most critical condition immediately after launch. Although Fig. 22 only shows the effect of axial loads due to longitudinal acceleration, bending moments due to *a* and *b* must also be considered in deciding the structural layout.

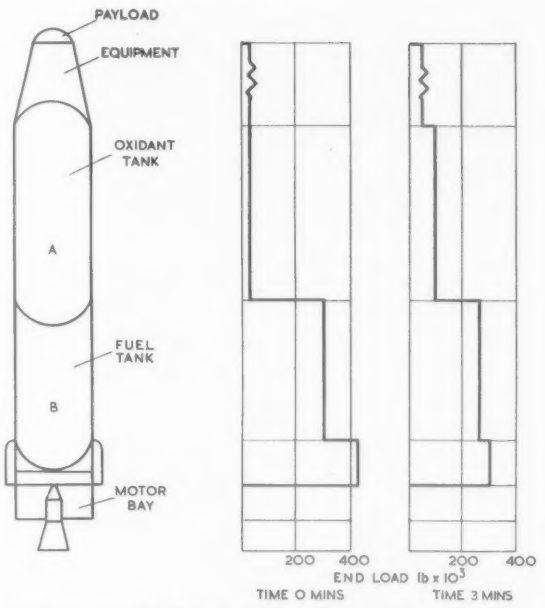


FIGURE 22. Hypothetical ballistic missile. Axial loading cases.

To preclude buckling of the cylinder under the combined axial and bending loads, either some form of mechanical stabilisation of the shell can be used, or an internal pressure can be maintained in the unstiffened shell so that the axial tensile stress produced reduces the axial compressive stresses (due to external loads), to a level which the shell can sustain.

In Fig. 23 a drawing of Blue Streak, produced from illustrations released in the popular technical press, shows external axial stiffeners in the region of the kerosine tank. Mechanical stabilisation of this type may, in certain cases, be preferable to pressure stabilisation, especially if there is a design requirement for the upper oxidant tank to be full when the lower kerosine tank is empty or unpressurised.

Figure 24 shows some design curves for long cylindrical unstiffened shells subjected to axial compression and internal pressure. The optimum design curves have been constructed using R.Ae.S. Data Sheets 04.01.01 and

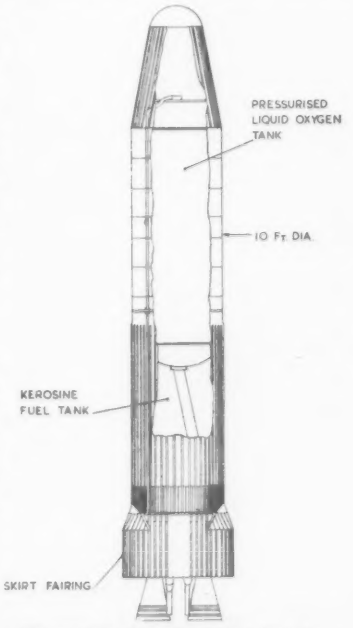


FIGURE 23. Sketch of Blue Streak.

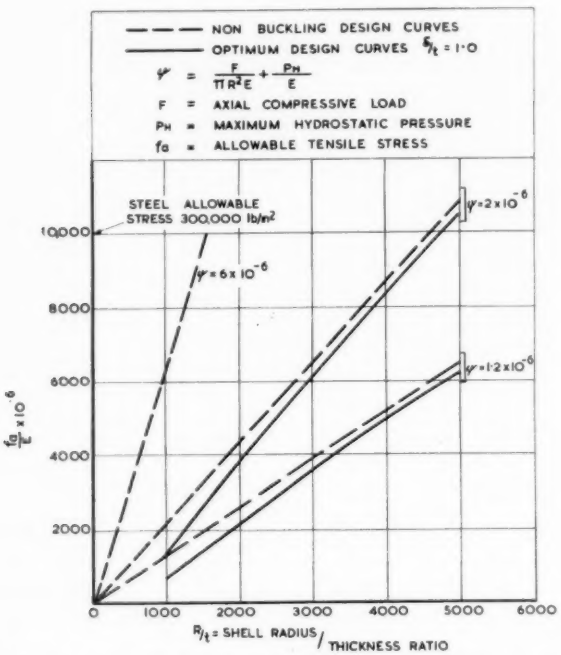


FIGURE 24. Design curves for long cylindrical shells subjected to axial compression and internal pressure.

correspond to a δ/t value of unity. Although as the data sheets show, the compressive buckling stress is increased by internal pressure, it is still relatively small and it is interesting to consider the results assuming that the internal pressure is such as to preclude the possibility of *any* axial compressive stress in the shell. This zero compressive stress was used in obtaining the "non-buckling" design curves in Fig. 24. For the values of external axial load anticipated for ballistic missiles it can be seen that the non-buckling curves are only slightly inefficient compared with the "optimum" design curves.

The design criterion used in Fig. 24 is that the maximum hoop tensile stresses should not exceed some allowable value, and in this respect it should be noted that these are caused by both internal gas pressure for stabilisation and hydrostatic pressure due to the liquid in the tank.

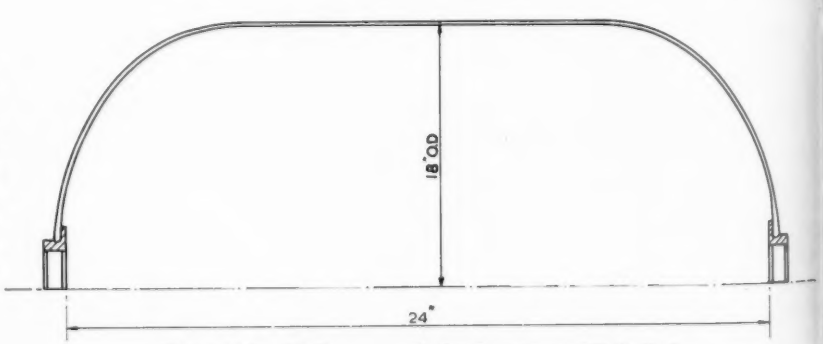
12. Filament Wound Pressure Vessel Design

The idea of winding a thread-like material in order to obtain high strength properties is not new since metal wire winding of tanks and pressure vessels has been used for many years. The filament winding method of fabricating reinforced plastic parts was first worked on about 12 years ago. It was about this time that continuous filament glass fibres suitable for this purpose became commercially available. The high strength to weight ratio of glass fibres is the main reason why this technique is being developed for pressure vessels and shell structures.

To fabricate parts the filaments are impregnated with a resin in order to prevent abrasion, and are continuously wound in varying patterns upon a mandrel, and then cured. Some of the early work associated with filament glass fibre winding was plagued with many difficulties such as resins, indifferent quality of fibres and inadequate winding equipment. Even at the present time the techniques for handling glass and impregnating it satisfactorily are not common knowledge.

Lamtex Industries Inc., U.S.A., are reported to have made plastic cases capable of withstanding hoop stresses up to 120,000 lb./in.² for Nike-Hercules, Little John, Bomarc, Pershing and Minuteman at one half the weight of similar structures in steel.

Hoffman[17] suggests that in a cylinder with its end-closures subject only to uniform internal pressure, made from a tight net system of high strength strands and with a low bonding strength between adjacent strands, the netting angle in the cylindrical portion of the vessel must be $\tan^{-1}\frac{1}{2}$, or a helix pitch angle of 63·4° with the axis. The end-closures would be chosen from a family of ovaloids whose shape is mathematically determined by the netting angle at the cylinder-closure juncture and the diameter of the opening. Such a design of cylindrical tanks, when taking into account practical difficulties of manufacture has resulted in conventional looking vessels with only marginally lower weight than the equivalent metal vessels. However, so rapid is the development in this class of structure that Fig. 25 shows a test pressure vessel which is demanded by one of the U.S.A. procuring departments to verify the manufacturing technique of filament wound plastic components. The diameter is approximately 18 in., the internal pressure 550 lb./in.², the hoop stress must meet a minimum value of 100,000 lb./in.² for a case weight of 5·4 lb. A steel vessel to have an equivalent weight would be required to develop a hoop stress of 416,000 lb./in.², a varying thickness over the ends and a thickness on the cylindrical portion of the order of 0·012 in.—a difficult specification to meet!



Case weight, 5·4 lb. Internal pressure, 550 lb./in.²

	Filament wound	Estimated steel
Hoop stress:	44·6 tons/in.²	186 tons/in.²

FIGURE 25. Filament wound glass fibre test pressure vessel.

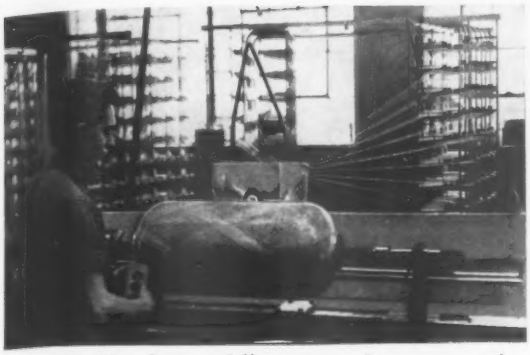


FIGURE 26. Manufacture of filament-wound pressure vessel.

Figure 26 shows a similar type of pressure vessel being made by Lamtex set up on a winding machine. Before winding, the automatic machine is programmed for winding angle, speed and spacing. Each filament is held under correct tension from the creel, through a resin-immersion bucket on to the mandrel. After winding, the structure, still on the mandrel, undergoes the first phase of a multi-stage curing process involving accurately controlled time and temperature cycles.

Research and development activities are encompassing the whole field of reinforced plastics, from high temperature resins, hardening agents and reinforcement materials other than glass fibre.

The applications of this technique to aircraft and missile radomes, missile nose cones, rocket motor cases and nozzles, structural tubing and high pressure vessels is already well known in the U.S.A. and to a much lesser extent in this country. However, because the specific strengths (*see* Table I) are now claimed to be 270 per cent better than H.T.S. and 235 per cent better than titanium, its application now that the specific stiffness is approaching that of the metals, must have a greater part to play in advanced aircraft, missiles and spacecraft. Fig. 27 shows a space probe made from the

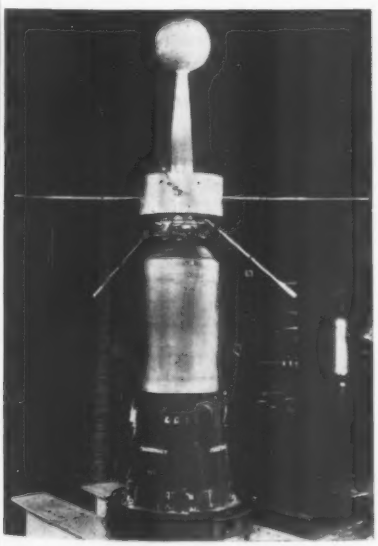


FIGURE 27. Filament-wound space probe.

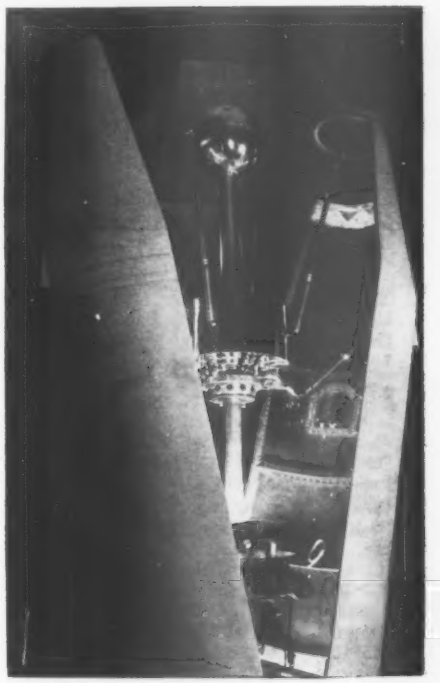


FIGURE 28 (*right*). Space probe inside nose fairing of launching rocket.

filament wound technique and Fig. 28 the finished probe, suitably plated, resting in its nose fairing.

A principal drawback to the production of reliable plastic vessels may be the means of attachment to bulkheads, nozzles, filler bosses, carry-through structures and the like. In spite of the many problems associated with this type of structure, ultimately it must have a bright future, not only on missiles, aero-space structural applications, but on common or garden aeroplanes.

13. Conclusion

In trying to review a subject which covers the structural trends from small aerodynamic missiles to the inter-continental ballistic missile it is obvious that many topics must be omitted. There is however very little factual unclassified information available on missile structures and within these restrictions it is hoped that some of the more important features have been covered. The approach to non-buckling pressurised shells is of interest and may or may not be valid practically, but it is theoretically defensible. More design data and development work is needed on thin shells employing high strength steels, and filament wound plastics. The use of

TABLE I

BASIC MATERIAL CHARACTERISTICS

Material	*Density lb./cu. in.*	*Tensile strength p.s.i.*	*Strength/wt. in.* $\times 10^6$	$E \times 10^6$ *p.s.i.*	*Stiffness/wt. in.* $\times 10^6$
Light alloy	0·097	80,000	0·83	10	103
Titanium	0·163	160,000	0·98	16	98
H.T. Steel	0·283	240,000	0·85	30	106
"Hystran"†	0·072	165,000*	2·29	3 to 7	41–97

†Impregnated glass fibre filaments (Lamtex Industries).
*Biaxially stressed hoop tension on the composite wall.

the ceramic braze adhesive could be of the utmost importance to all classes of supersonic vehicles.

If this review has in any way shown that there are other things in missiles besides warheads, guidance control and propulsion systems, then its object has been achieved.

ACKNOWLEDGMENT

The author expresses his sincere appreciation of the help received from many friends in industry and his colleagues, particularly D. S. Houghton and D. J. Johns.

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Following the lecture, a film was shown of the use of Tape Controlled Welding Equipment in the manufacture of the Terrier missile wings. The film, made for LINDE of the U.S.A., was kindly loaned by the British Oxygen Company. The lecturer pointed out that the type of "puddle" welding was similar to that used on the Bristol 188 aircraft, but the technique of arc control was different.

SUMMARY OF DISCUSSION

J. L. Crowder (Head of Structures Dept., Guided Weapons Division, English Electric Co. Ltd., *Associate Fellow*): Of all the topics covered by Mr. Newell the one that intrigued him was this controversial question of safety factors. He felt that if they were to adopt a unilateral reduction of safety factors in this country the ultimate benefit might not be as great as one would expect.

He agreed in theory that if they were able to estimate their limit loads precisely and were able to undertake perfect stress analyses, then they would have a hundred per cent structural reliability, even if they had proof factors of one and ultimate factors of 1·1/4. But if one adopted a reduction of safety factors, two things were liable to happen. One was that they could suddenly be faced with a crop of structural failures which might show up late in a development programme and this would be expensive in terms of time and money. Two, the stressmen and the aerodynamicist would say they had no margin of safety on their estimation for the limit load and would slip in another "10 per cent for luck," and one would have lost the apparent gain due to reduced safety factors. However, it seemed somewhat arbitrary to adopt the same safety factors for all missiles for all conditions of flight. In missiles the limit accelerations and thrust levels were precisely known, or one could build in limiting devices, but the associated distribution of aerodynamic loads to go with these appropriate accelerations were not known accurately. With internal components of strategic missiles they could define the exact nature of the limit load if based solely on acceleration criterion, so it might be worth considering the uses of lower factors for components stressed solely by pure inertia loads, or have as their dominant stressing case loads which were almost entirely thrust and inertial in character.

For components loaded by forces of mixed origin, part aerodynamic and part inertial, it would be dangerous on the grounds of time and cost, to accept a unilateral reduction of safety factors, because there were times when they did not discover some stressing cases until they had started flying missiles. Those were his personal views and not necessarily those of his company, but he would be interested to have suggestions from missile designers. There was the question of safety factors as applied to thermal stresses. Probably the greatest variable associated with heating was the heat transfer coefficient, but if one factored this it must be adjusted to suit a variety of loading, temperature and thermal gradient distributions which did not necessarily coincide at their maximum values.

Mr. Newell: The thing that was at the back of his mind when comparing missiles and aircraft safety factors was that missile factors were whittled down aircraft factors. He might be wrong, but one would have thought in a one shot, non-recoverable vehicle, parts might be allowed to deform plastically so long as the elongation and rigidity requirements were met after the mission had been accomplished. One would have thought that a statistical approach as outlined by Anderson[4] would be a natural thing to do. The general impression he got from some missile designers in America was that they did not want to be tied down to safety factors, they wished to be the design authority for their particular missile and guarantee the degree of reliability. Would British designers like that?

Professor G. A. Whitfield (Head of Dept. of Aircraft Electrical Engineering, College of Aeronautics, *Fellow*): Speaking on behalf of the electrical man, there was always a tendency to say that electronics were susceptible to failure, therefore they saw a higher reliability on the airframe than the rest of the system. The structural man, particularly in aeroplanes, took all the extra structure weight to get his factors up by the odd 10 per cent. The competent electrical designer was disciplined down to such low weights that he could not get high reliability. A recent example in generating equipment had given the designer the deplorable job of getting performance at low weight but no reliability—he got the unreliability he expected. There was a complete unbalance between reliability and weight, and if the structural man reduced weight a little bit, other people could get a little bit of reliability

Mr. Newell: Professor Whitfield spoke of aeroplanes instead of missiles. He believed the aircraft constructor, not the component manufacturer, had the ultimate responsibility for the aircraft including the components. In most aeroplanes there were a number of subcontractors and if a particular subcontractor could not meet his target weight with adequate reliability, then the fault was with the aircraft designer, who had either chosen the wrong system, or the wrong manufacturer. There was never any question of giving preferential treatment to the structures man.

C. K. Trotman (Senior Lecturer, Dept. of Aircraft Design, College of Aeronautics, *Associate Fellow*): The reliability of any complex system was often derived from the product of the reliabilities of the individual items. In such cases if one doubled the reliability of the least reliable component one doubled the reliability of the system.

Referring to Mr. Crowder's point of what sort of factor should they put on thermal stresses; they had to throw out the idea of safety factors. He suggested they had to decide on certain structural probabilities in the heat transfer coefficient and on the temperature lying within certain limits. The thermal stresses were derived from those quantities and once one had laid down the limits one was expecting from these various quantities, then one had a fixed probability of the thermal stresses which were to occur between these fixed limits.

Mr. Newell: Mr. Trotman's points were perfectly valid. The point was, how did one achieve that in practice? Let them accept the suggestion that a reliability group should be set up inside the missile firms and the problems of reliability solved on a statistical basis. If they now complicated the matter with thermal stresses, changes in material properties and temperature distributions, sometime, somebody had to be given a number or a stress to work to. If all this were to be arrived at on a probability basis, then it would be a complicated and tedious task of which not the least problem would be staff organisation.

A. V. Cleaver (*The Chairman, Fellow*): On the question of electrical equipment reliability there was a considerable difference between the manned aircraft and the missile. In the manned aircraft the structure must not fail, but one could often afford to let a system fail. In the missile, whether the failure was in guidance, electronic equipment or structure, the effect was often equally disastrous.

Mr. Newell: This might have been so in the past, but if they were to have $M=2$ or $M=3$ supersonic transport aircaft, they would be more like missiles.

D. Howe (Lecturer, College of Aeronautics, *Associate Fellow*): Mr. Newell commented briefly on the fact that in some quarters there was a tendency to regard the missile structure as of little importance. The result was that in this country during the days of early test vehicles, the missile was treated as though it was simply a flying "black box". This attitude did not stem from the early German work where many missiles were designed by aircraft firms. For example, the Enzian was a Messerschmidt design.

Fortunately sanity had now prevailed and it was a pity that some of the structural concepts of current weapons could not be discussed. As the lecture had dealt with the missile structure in a qualitative way, he would like to show in a quantitative manner what had been achieved in missile performance, by structural improvement.

Table A showed various missile weight breakdowns. The "typical weapon" did not apply to any particular weapon, but was based on design studies done at the College of Aeronautics. With the rocket propelled surface-air missile the increase of structure weight resulting from early attempts at supersonic design was apparent. With the "typical" weapon there was considerable saving in structural weight and the 25 per cent might be a little pessimistic if compared to modern weapons. The gain in structure weight for ballistic missiles was even more noticeable. It was true to say that the large liquid rocket vehicles that they knew today had become possible as a result of the structural techniques discussed in the lecture. In fact the only major improvement which could now be expected was for the propulsion expert to learn how to use all his propellant.

TABLE A

MISSILE WEIGHT COMPARISONS

Rocket propelled Surface-Air Missile (Unboosted)

	Enzian Hs	*117*	*Early Test Vehicle*	*Typical Weapon*
Propulsion, tanks and system	9	29	15	10
Structure	13	25	35	25
Guidance and payload	33	12	15	18
Control and power supplies	8	6	10	12
Propellant	37	28	25	35
Total	100%	100%	100%	100%
	Subsonic		Supersonic	

BALLISTIC MISSILE

	V2	*Typical large weapon*	*Reduction*
Propulsion system	3·7	1·8	~50%
Structure and tanks	14·35	2·5	~82%
Guidance and payload	8·35	5·0	
Control and power supplies	5·8		
Total propellant	67·8	~90·7	
TOTAL	100·0%	100·0%	
Residual propellant		0·7% to 1·0%	
Mass ratio	~3·0	~10·0	

K. G. Harrold (de Havilland Aircraft Co. Ltd.): A lot of interesting work had been done by de Havillands which unfortunately could not be released. The environment of the tank shell—to stand for several hours at 190°C and then within three minutes reach approximately 450°C—put severe demands on the materials and the construction. They were constantly looking for new materials and for better manufacturing techniques and he thought the next step would be the development of more exotic materials.

He was very interested to see the film of the tape controlled automatic welding. They had a variety of welding machines all developed by themselves; none were automatic, but they had cost very little and had proved extremely satisfactory. He did agree, however, that in the country at large, too little was spent on development of materials and manufacturing techniques.

J. F. Cuss (Chief Stressman, Gloster Aircraft Co. Ltd., *Associate Fellow*): He was surprised at the attention concentrated on the question of strength and safety factors and considered that stiffness and fundamental frequency requirements were more important on primary structure. Also, the incidence of large openings in the sides of shell structure would contribute to the lack of stiffness.

J. L. Crowder: Stiffness was important and was well catered for, but the way the discussion had been going the emphasis was on designing a structure for minimum weight. It should be remembered that the aerodynamic tactical missile was a piece of artillery and had to be designed to meet service requirements, including the environments of fatigue and combat handling. The weight put into a missile by joints and access panels to make it an acceptable weapon was probably greater than that of an "idealised" primary structure, but in this latter case it would be no use as a weapon and would have to be handled in cotton-wool. And on the score of handling there was a great difference between the tactical weapon and the space vehicle.

A. J. Barrett (Head of Technical Dept., R.Ae.S., *Assoc. Fellow*): Because the work of Klein and the Royal Aeronautical Society Data Sheets did not agree, it did not follow that one or both were wrong. He would defend the critical irregularity term of δ/t as affecting the buckling, pointing out that the Royal Aeronautical Society Data Sheets only applied to Elastic Buckling.

Astronautics and Guided Flight Section

The Training of Guided Missiles Engineers

A SUMMARY OF A SYMPOSIUM

BY

J. L. NAYLER, M.A., F.R.Ae.S., F.I.A.S.

An All-Day Discussion on the Training of Guided Missiles Engineers was held by the Astronautics and Guided Flight Section of the Society in the Lecture Theatre on 16th March 1961. The Chair was taken by Mr. A. D. Baxter, M.Eng., F.R.Ae.S., M.I.Mech.E., F.Inst.P., Executive Director (Engineering), de Havilland Engine Co. Ltd.

Introductory papers were given by L. H. Bedford, C.B.E., M.A., B.Sc., A.F.R.Ae.S., Director of Engineering, Guided Weapons Division, English Electric Aviation Ltd.; Ian Dean, M.A., Education Officer, de Havilland Aircraft Co. Ltd.; F. G. Tarrant, Assistant Director, Guided Weapons (Engineering), Ministry of Aviation; Professor G. A. Whitfield, B.Sc., F.R.Ae.S., Professor and Head of Department of Aircraft Electrical Engineering, College of Aeronautics; Commander E. G. Allen, R.N., Professor of Naval Engineering, Royal Naval College, Greenwich; Professor C. Holt Smith, C.B.E., M.Sc., M.I.E.E., Head of Department of Electrical and Instrument Technology, Royal Military College of Science, Shrivenham; and Wing Cdr. G. C. Wainwright, B.Sc., A.F.R.Ae.S., A.F.I.A.S., Chief Instructor, Weapon Systems Engineering Wing, R.A.F. Technical College, Henlow. The Discussion was opened by M. J. Armstrong, Chief Training Engineer, Bristol Aircraft Ltd.; Professor E. J. Richards, O.B.E., M.A., D.Sc., F.R.Ae.S., Professor of Aeronautical Engineering, University of Southampton; Colonel J. P. G. Lewis, War Office (Directorate of Equipment Production), and Colonel W. J. Mellors, M.B.E., School of Electronic Engineering, R.E.M.E. Twenty-three other speakers took part in the General Discussion.

IN THE MAIN the discussion ranged around the desirable qualities and training of the top-flight men from the points of view presented by the industry, by government departments, by the universities and colleges and by the users, the last-named being represented by the three Services with their own training arrangements. The desirability of having good men, technologists and others, to support the top-flight men was not wholly neglected. Somewhat contrary viewpoints came naturally from the teachers, the producers and the users.

Subjects for Study

The main subjects of guided weapons are aerodynamics, structures, propulsion, guidance and control; of these only propulsion and control are new subjects needed for guided missiles. Propulsion is a natural development starting with piston engines and leading through turbines to rockets, so that rocketry in its main aspects is not anything fundamentally novel, a view expressed at the beginning of the meeting and not contradicted later. Thus, the main new subject for study is that of control, and here great difficulty has been experienced in industry in finding and training staff. In this region there was a major issue where the educationalist could help; other subjects are mentioned later. At present, systems people are usually picked out from others when it is found that they have been developing a special aptitude, and after some formal and general training in an Education Department, are sent to a number of departments in turn. Systems engineers were never found ready-made, although servo-mechanics, feed-back systems and other aspects were more widely taught now at college and university than ten years ago. No one solution was offered to the problem as to how good systems engineers could be made available and opinions differed as to whether any training should be given in the firms, whether reliance should be placed on external sources or whether suitable men should be picked when their capabilities in this direction became apparent: in general, a systems engineer needed a very broad background to understand repercussions of other than his own specialised knowledge on the whole project.

Constitution of Guided Missile Staffs

A speaker gave figures for the staffing of one division of a firm dealing with guided weapons: 25 per cent had qualifications of higher national certificate or above; 70 per cent of the latter had degrees and over half of the last were physicists and mathematicians who had the basic knowledge for application to guided missiles. Others below the top-flight were educated to an appropriate level of engineering training: H.N.C., O.N.C., etc.

General Training

One large firm stated that 10 per cent of the total staff were having formal training under the control of the Education Department. Most firms encouraged their staff to improve their education by taking courses for the Ordinary and Higher National Certificates at technical colleges for which there was day release and also by attendance at special courses.

For more specialised training in their Education Department one large firm selected 15 persons per year; these persons visited a number of departments in turn. Another firm had information courses for both graduates and non-graduates during which they also learn about other departments. A two-year specialised training for graduates in the firm itself where they were employed was favoured by all speakers from industry.

Universities were criticised for the time lag measured in years between the adoption of new methods and devices in industry and any instruction about them in an educational course. Replies were made to the effect that industry was slow in asking for what it wanted, that adequate communication between industry and university was lacking, except perhaps in one case, that the missile field was secret and that the first duty of universities and colleges was to teach basic knowledge.

Academic Training

American training like that at M.I.T., California University and Johns Hopkins University produced, with its part time on weapon systems for government contracts, the right type of engineer. An H.N.C. qualifi-

cation with apprenticeship was inadequate for the top-flight engineer. Steps have been taken in this country, as at the College of Aeronautics, to give post-graduate training of the type required. The College claimed that its training was much the same as that in the U.S.A.

The academic training at university or college should be broad and cover the basic fundamentals of several subjects before post-graduate training led to specialisation in one, or better still two subjects. This was agreed by all. At one post-graduate college 25 students, wholly post-graduate and already expert in one or two branches, were on a one-year course, half-time on specialisation and half on broadening each student's knowledge. This course was supported by 8-10 countries, but there were no British students since no firm had agreed to spare a man for a minimum of 9 months. Other students at this college spent a first year broadening their knowledge and specialised in the second year.

One speaker was in favour of a total of six years training as necessary to produce a first class engineer with enough experience to cover all the aspects of design, test, trials and production essential for the efficient development of a reliable guided weapon. To consider the missile alone was not enough as the guided weapon engineer had to conceive the weapon system as a whole and this was an exceptionally difficult problem. This length of training was costly but it was a small price to pay towards a very expensive missile. Such a lengthy preliminary training was not considered necessary or desirable by most speakers, and one industrial representative thought it out of the question; a one-year post-graduate course might be appropriate.

Universities had a duty to train students in every field of engineering and no professor was a specialist in missiles. Electronics could not be given the same weight as many other aeronautical subjects such as aerodynamics; modern servo mechanisms and automatic control were recently receiving attention at more than one college, but they had applications other than in the missile field. Research and post-graduate courses were also included in more than one university's curriculum. Short refresher courses were available on special subjects at some universities and colleges, but the response from industry was not as good as had been expected. It was a pity that no more advantage was taken of the Universities' efforts.

Special Guided Weapon Courses

Firms were strongly in favour of short specialised courses as it was difficult to release men for a period of three months or even for one month. A comment was made that nine months out of forty years was a short period taken from a life's work at a firm and although the release for this period might affect the execution of a particular contract it would doubtless repay both the firm and the individual; in reply it was stated that release was difficult because of the short time scale in industry.

The Services

A Service man has in the first instance to meet the requirements of his particular branch in each of the three fighting services and within that framework to operate the missiles produced by the industry; for example, the training of the naval officer must include the ship. For this reason, each service has its own training scheme of two to three years, added to which are the studies for the operation of different weapons, including the guided missile as one specialised weapon.

The Navy entrant at 18 years old has passed the G.C.E. at Advanced Level. His naval and ordinary engineering training is supplemented by a degree course at the Royal Naval Engineering College, Manadon, or at Cambridge University in either Electrical or Mechanical Engineering. A Weapons and Radio Engineering Specialisation course of one year follows and a period at sea. Some honours men from Manadon or Cambridge are selected for an Advanced Weapons Engineering course lasting two years under highly qualified and experienced academic and professional engineers. At Greenwich Naval College the course tends towards a combined Mechanical and Electrical engineering basis and a co-ordination of all arbitrarily separated subjects. This Advanced Ordnance Engineering course includes all aspects of missiles plus a design study development of one missile, the special ship requirements, underwater problems and simulator studies.

The Royal Military College of Science at Shrivenham has been giving guided weapon courses since October 1950, including an industrial course of five weeks that ran for a number of years and could again be restarted now that more staff were available. The main Guided Weapons course is for officers who have already taken the Staff course. After a preliminary course the main course deals with guidance and control, performance and stability, dynamics, warheads and trials. The greater emphasis is on the two former and on Applied Studies, which include a Design Exercise and a thesis. External lecturers assist in the teaching of students who are not required to take any formal examinations. At the Indian Institute of Armaments Studies, an equivalent of Shrivenham, a G.W. course was started in 1960.

The Army is interested technically in the development and maintenance phases as well as operation. Basic education for the R.E.M.E. officer is a normal University degree course (Cambridge or London) on which the officer may be directed to the subjects to be read, and this is followed by specialist training in guided weapons which have to be regarded as one, although admittedly the most complicated—of a number of weapons. Hence the fundamental requirement is for good engineers rather than specialists.

In addition to being the major operators or users of guided weapons, the Royal Air Force participates to a wide extent in the research, development and introduction of weapons systems into the Service. Training of officers has expanded in phase with the increasing research and development effort as well as with subsequent deployment and use of guided weapons. R.A.F. officers were originally specialised as Engineers, Armament and Signals and now as Mechanical or Electrical Engineers. Weapons training embraces a much wider field of applied science and technology and current training courses include revision and extension of basic theoretical knowledge, cross training between specialisations

and finally the study of advanced design techniques. The earlier emphasis on guided weapons has given way to the weapons system approach.

The current Advanced Weapons Course is of 15 months' duration for officers of graduate level generally in their late twenties. The basic phase includes Mathematics, Chemistry and Nuclear Physics; the applied phase Thermodynamics, Aerodynamics, Electrical Engineering and Electronics, Control Engineering and Computers; and the weapons design phase Missile Control and Guidance, Missile Propulsion, Warhead and Weapons System studies. The final term includes a project/thesis and weapon design study. Officers are posted, initially at least, to research or development.

Shorter courses of some six months' duration are conducted for both Technical and General Duties officers who will be largely concerned with the operating and servicing of weapon systems, together with a one month course for senior staff officers. The Weapon Systems Engineering Wing comprises Control, Guidance, Warhead and Propulsion and Systems Analysis Squadrons. R.A.F. officers, officers from Commonwealth Air Forces and from the other Services are included in the courses. The systems approach is considered as fundamental to this sphere of technology, "guided weapons" being but a part of the system.

Hardware

Whereas there is no lack of persons whose academic training makes them capable of solving basic problems, this country falls down in its ability to produce hardware that will function satisfactorily. Faulty detail engineering has led to numerous modifications. What is wanted is hardware that is reliable and will give no trouble for, say, 200 hours. Specialised Guided Missile engineers brought up to think only of guided missile systems are needed according to some speakers; others preferred engineers with general all-round training. The users were insistent that the hardware should be of a much higher standard of reliability when firms send it to the Services for firing trials; as much as 20 per cent of the time from design to useful service could be saved by careful attention to all details.

Need for self expression and communication

Many speakers drew attention to the difficulty arising from the inability of staff to assemble, and to transmit in an intelligent manner, information to others working with them and even more so, to persons working in another section. For this purpose information courses were essential whereby graduates and non-graduates learnt about other departments; in addition, they still needed training either then or earlier, preferably at university or at college, to be able to transmit this information intelligibly to others. General agreement was expressed with the opinion that a basic degree course should include training in self expression.

References were made to the constant grind of meetings in the missile industry where much could be done to increase their effectiveness in reaching decisions if those in attendance had been previously trained in self expression and communication; this could only be acquired at a university or very gradually after a number of years in industry.

The Individual

Stress was laid on the outlook of the Guided Missile engineer. It was important that the better men should be attracted by adequate remuneration, that there should be less uncertainty about the industry's future and that the individual should not be sacrificed to the project. The incentive to younger men was largely negative, because industry frequently appointed senior engineers from outside.

In the aeronautical world, and especially in guided weapons, the individual going to a firm for a vacation was only engaged on a particular aspect, often did not know what he was doing and so got fed up; the same applied to some graduates. Although the final product is complicated, industry might try to improve the outlook for the individual so that he can understand and appreciate how the bits and pieces fit into the whole.

A long course of continuous training is not attractive to youngsters, but a systems engineer at 25-30 years might welcome, and would certainly benefit from, further training to widen his outlook. At the 30-year level it was astonishing what could be both learnt and accomplished. One firm had decided to sponsor certain young men with good honours degrees on post-graduate courses lasting a full academic year.

While bearing in mind that there was a greater diversity of opinion at the meeting than can be expressed in a few words the main points arising from the discussion can be briefly summarised as follows:–

(1) The research and development aspects of guided weapons need a concentration of good sound engineers as a primary requirement.

(2) The best men cannot be attracted to, or retained in, the guided missile side of the industry unless they are sufficiently well remunerated.

(3) Good men in the industry should, when they show sufficient promise, be sent for post-graduate training at, say, about 30 years old. Firms were stated not to be able to spare such men except for short courses.

(4) The proposal in (3) may ultimately produce more valuable staff than men who first complete a long continuous training with no break in industry.

(5) Opinion was divided as to whether it was preferable for later training, *e.g.* post-graduate or post-H.N.C., to be given at a firm or externally. The Services have their own training courses for their particular needs as users, and firms have their training schemes.

(6) Universities and Colleges should be encouraged to pay more attention to training students in self expression and communication of technical information.

(7) More universities might with advantage introduce some of the new technology at undergraduate level.

(8) A serious lack of liaison exists between the academic staffs at universities and colleges and the guided missiles industry.

(9) The Royal Aeronautical Society might take some active steps—following on this discussion—to arrange for a co-operative effort to bring closer together the industrial and academic aspects of the training of guided missiles engineers.

The Royal Aeronautical Society
The First Fifty Years

BY

J. LAURENCE PRITCHARD, C.B.E., Hon.F.R.Ae.S., Hon.F.I.A.S.

1871 - 1873

"There was a considerable attendance of members," says the Sixth *Annual Report* of the Society of the meeting held on 17th July 1871, with James Glaisher in the Chair.

The "considerable attendance" was not unexpected. The siege of Paris had drawn attention to the value of using the air for transport and mail in time of war. It was true that the besieged in Paris had to rely upon the way the wind blew and balloons, but enthusiasts of the Aeronautical Society were convinced that a heavier-than-air machine was not only possible, but would avoid all the drawbacks of the balloon being blown where the wind listeth. A large number of attempts had been made to make the balloon steerable, but with insignificant success.

Richard A. Porter, the well-known astronomer, suggested in a letter the use of a gyroscope to obtain the necessary stability of a plane, and added, "I believe that the principle of the gyroscope will enter importantly into the construction of the aerial machine of the future," a statement of some considerable foresight.

A member, G. S. Hall, put forward the use of aluminium for wing construction, in order to get the lightest possible aircraft.

A. Alexander, a member of Council (and father of that P. Y. Alexander who did so much for British aviation in later years and became a friend of the Wright Brothers), in a paper on man powered flight, declared "Far from wishing to discourage inquiry on the part of those who may think otherwise, I have long been of the opinion that one's muscular exertions will be found, in all cases, quite inadequate . . . and that to accomplish aerial navigation in a comprehensive sense we must obtain a proportion of power in relation to weight considerably greater than we at present possess."

Alexander was a fully qualified and practical engineer and his statement carried considerable weight at the time.

The problem of pressure and speed was one which was constantly under review those days and Wenham took the opportunity of presenting a paper on experiments by J. Spiller, M.Inst.C.E., prepared some twenty years before the Society was founded. Written in January, 1846, its purpose had been to ascertain the law of resistance to the passage of air through pipes of different diameters and lengths, at various velocities. The experiments had been done in connection with a project to drive trains through tunnels by air pressure. Wenham drew the attention of the audience to the importance of the data obtained "as they will afford comparisons for connecting the law of pressure and velocity in aerial currents."

In an interesting paper entitled "Thoughts upon the Present Position of Aeronautical Science," H. M. Sykes argued the case for fixed wings and flapping wings, and for the use of man power for flight, with the object of persuading members to make up their minds which method to try. Sykes was quite definitely against man being able to fly under his own power, as he was against the flapping wing. Alas, however, he was forced to the unhappy conclusion that with fixed wings it would be necessary to fill much of the fuselage of his proposed aeroplane with gas (or even a vacuum).

Mention has already been made of the work of de Lucy and Marey on natural flight and also of the fact that many medical men took considerable interest in the possibility of flight. One, Hugh W. Diamond, had been a member of Council from the beginning. In the 1871 *Annual Report* appeared a communication from Dr. J. Bell Pettigrew of Edinburgh, a member of the Royal Society, on a "New Form of Propeller" for water and air. Pettigrew had for many years made a study of the flight of insects, birds and bats, and had anticipated Marey in describing the movements of the wing tips of birds and insects in flight, in a paper to the Royal Institution and one to the Linnæan Society in 1867. Three years later Pettigrew presented a paper to the Royal Society of Edinburgh to show how the wings of birds and insects and the tails of fishes acted as air-screws. In his communication to the Aeronautical Society Pettigrew suggested flexible reciprocating air-screws as being the most efficient for flight. He ended his letter with the words, "I have taken the liberty, from time to time, of submitting my papers and memoirs to the Aeronautical Society, in the hope of explaining to its members what I regard as the physical basis of swimming and flying. The views in them have derived additional interest and significance from having been confirmed by the researches and experiments of Professor Marey, M. Senecal, M. de Fostes, M. Ciotti and others."

This communication was immediately followed by extracts from Dr. Marey's paper on the "Mechanism of Flight in the Animal Kingdom," translated by T. J. Bennett from *L'Aeronaute*. Further extensive extracts were given at the end of the 1872 *Report*. Marey himself had acknowledged Pettigrew's priority in the "figure of 8" loop described by the wing tips of birds and insects.

If members of the Society could not fly there was no dearth of offers to find out how birds were able to do so. Pettigrew's and Marey's communications were followed by one from David E. Gosling, a civil engineer of Bombay, on bird flight.

"Let us give Nature a chance!" declared the well-named Gosling. "India offers superb soaring experience from a bird's point of view, for vultures, eagles, herons, kites, adjutants and cranes," Gosling listed as the birds which had mastered the art. He gave some interesting estimates of the climbing rates of birds. "No bird can rise in a perpendicular direction quicker than four feet in a second, two feet would be nearer the average, and, for a great height, one foot per second would be the utmost that could be obtained. Upon this estimate it would take a vulture upwards of an hour to reach a mile in height, and this is probably correct."

The whole of Gosling's observations were acute, but his conclusions were not always so. He deduced that

what a bird could do, so could a man, with practice. Gosling was crowing out of turn.

At the end of the *Annual Report* there was published an account of the Council's experimental research on the pressures on flat surfaces in a stream of air.

The experiments had been carried out in the Engineering Works of Messrs. Penn at Greenwich. A wind tunnel, some ten feet long and a foot and a half square, had been designed by Wenham and Browning. The current was supplied by a fan. Four flat plates, one a square of one foot side, a second a circular plate of one square foot area; a third, 4½ in. by 18 in., 81 sq. in. area; and a fourth 18 in. by 9 in., 162 sq. in. in area were used.

"The plane to be acted upon was fixed to the long end of a horizontal arm, which vibrated like the beam of a balance, and bore upon its shorter end a sliding counter weight, so as to balance the weight of any plane which might be fixed at the opposite extremity. The horizontal or direct pressure was read off by a spring steelyard, which was connected to the end of a lever from a vertical spindle close to the base of the machine. The vertical or raising force due to the various inclinations was read off by an upright spring steelyard."

Measurements were made at angles of 15°, 20°, 45°, 60° and 90°, and the conclusion drawn that the lift of inclined planes "is increased in the direct ratio that the sine bears to the length of the plane, or the height of the incline to the base; thus, if instead of stating the angles in degrees, we say 'one in ten' or 'one in three or four' as the case may be, this will at once express the proportion in which the lifting force exceeds the resistance."

Although more acute angles than 15° were not experimented with, the conclusion was drawn that at very acute angles of attack the ratio of the lift to resistance was very great, "and alone serves to abate the mystery relating to the support of weight in flight."

The Council realised that these first experiments were "somewhat crude and incomplete," and stated "it is desirable that these important experiments should be verified and continued . . . up to the present time only flat surfaces have been experimented upon, and as all the sustaining surfaces in the wings of birds are curved or hollow, it remains to be proved what is the relative advantage of this form, for it is upon such data that all plans and construction must be based, and on which failure or success must depend."

"The Society may congratulate itself," said the 1871 *Report*, "for having been the means of bringing and recording a number of facts not lost upon its members, which have produced greater unanimity of purpose, and have, it is presumed, directed the efforts of experimentalists in accordance with a more generally recognised and practicable theory."

These were the first wind tunnel experiments in the history of aviation and, although crude, inconclusive and inaccurate, they must rank among early pioneering experiments in other branches of scientific research.

The only meeting in 1872, on 18th April, began by Wenham explaining the experiments which had been carried out on air pressures. The wind tunnel and other parts of the experimental apparatus were shown to the audience at the lecture, the first of its kind read before the Society. Alas, no drawings have been found of the apparatus.

Glaisher, in the course of enlarging upon Wenham's remarks, drew attention to the boundary layer, ". . . the particles of the fluid which came in contact with the plane have somehow or other to get out of the way, by gliding along the surface of the plane (as they cannot get through it) and this *produces a complication in the neighbourhood of the surface of such a kind as cannot be theoretically predicted.*"

The italics are mine.

Glaisher drew attention to the fact that the measurements made were only accurate to the extent to which the instrument could measure them, and that certainly some of the measurements were uncertain. Charles Brooke, F.R.S., another member of Council, also considered the problem of the boundary layer.

"The simple geometric considerations of the action of the pressure upon the plane, did not involve the necessity for the particles of air which had impinged upon the plane, getting out of the way to enable other particles to impinge upon it."

In the course of the discussion which followed, R. Harte, himself a keen experimenter and the author of a paper on the "Theory of Flight," asked pertinent questions about the movement of the centre of pressure, particularly whether it moved forward.

"We found as the angle became more acute," replied Wenham, "the centre of pressure came nearer to the front edge."

A visitor from New Zealand, a Mr. Head, gave a lecture on bird flight, particularly with reference to the albatross. Wenham, during the discussion, showed what a tower of strength he was, for he never allowed members to forget that ultimately flying was an engineering problem, and the engineering principles involved could not be biased in favour of a bird or anything else which sustained itself in the air. The lecturer had said that he was not sure that an albatross could fly except in a gale.

Wenham had taken great care to explain that what mattered was the relative speed of the bird in the air. "It may be a fifty mile current, and if the bird makes that speed in flight, in the direction from which the wind comes, it will make no progress relative to the ground, but in the opposite direction will speed on at the rate of 100 miles an hour, yet its progress through the body of air will be identical in both cases, fifty miles an hour."

Members argued against Wenham at length, on the false analogy of a kite being flown in a wind and held by its string.

So ended the first seven years of the Society's existence and it may well be asked, in view of this kind of argument at the end of these seven years and of some of the poor papers published in the *Annual Reports*, what had the Society accomplished, and was anything done to have justified its existence?

The justification for existence at all is one of the more difficult of philosophical problems. The justification of the existence of a Society devoted to aeronautics in the Victorian era is, perhaps, not quite so difficult.

Glaisher did yeoman service in the first seven years of the Society's existence, presiding at meetings of the Council and members, keeping the flame of hope burning, and interesting and inducing many influential people in other spheres of science and engineering to join. He and Wenham were undoubtedly the two king pins of the early structure, without whom it would have collapsed, despite the extraordinary energy and enthusiasm of Brearey.

The Society's meetings revealed from the beginning that there were many enthusiasts with solutions of the problem of flight, solutions based almost in their entirety on theories derived from observations of bird flight and little, if any, on practice. Wenham and others

impressed upon the Council the importance of obtaining certain necessary data before any real progress could be made, and the initiation by the Council of the first wind tunnel experiments was, in itself, justification for the continued existence of the Society. Ever since that day the importance of aeronautical research has been the theme song of the Society.

Lighter-than-air projects were not accepted lightly, however! In the Concluding Remarks for the beginning of the second seven year period there appeared the following,

"It is simply astonishing to hear of people trying year after year to drive elongated balloons, or gas bags of the form of a German sausage, with a car beneath it, and a *screw* of course. This is generally the first conceived project of any one commencing to think upon the navigation of the air, and each fancies himself the happy possessor of the secret. Yet what a very small amount of science is necessary in order to show its fallacy."

The plausible, but unscientific arguments which followed, did not prevent the successful development of the dirigible in later years or the discussion of Dupuy de Lome's famous man-power dirigible by Glaisher at the opening of the next Annual General meeting in 1873. But Brearey lost no opportunity of attacking the gas man and this added at intervals to the levity of the discussions and *Reports*.

The *Annual Reports* do not reflect fully the activities of the Society and its members. Brearey, for example, was in constant touch with the editors of *The Engineer*, *Engineering* and the *Mechanics Magazine*, so that he could get the latest news of any possible aeronautical development and, in turn, get news of the Society's activities published in quarters where they would be studied. He met with only varying success in his endeavours, for engineers, as a body, do not let their imaginations run riot easily.

Brearey actively helped members where he could. For example, a Mr. Richard Harte, who wrote a pamphlet on the "Theory of Flight," constructed an aeroplane model on a large scale, an achievement not mentioned in the *Annual Reports*. On 3rd October 1871, Brearey wrote to John Stringfellow,

"You may perhaps remember a Mr. Harte who wrote a pamphlet which he sent to all our members. I went to see him yesterday at his request and I thought I saw an opening for some almost immediate result. He has constructed an aerial machine, the photograph of which he showed me. Dimensions are as follows—each wing 21 feet—space between for himself 1½ feet—therefore from tip to tip 43½ feet—surface 300 sq. feet—weight about 75 lb.—so that here there is sufficient surface to carry himself and steam engine, for he is a small but muscular man. He begged me to write and ask if you would grant him an interview and show him the action of your screws, for hitherto he has moved the wings by his manual power—not quite unsatisfactorily. It is almost certain that if that engine were finished you might have a good return from it. If your reply is favourable he will go to Chard to see you."

But Stringfellow did not complete the engine. He had many offers for light engines, but his health and failing eyesight prevented him from carrying out the commissions offered to him, and he refused to let a workman, however skilled, work on his models.

In 1872 Moy and Shill were busy with the design and construction of their Aerial Steamer, and many entries in Brearey's expenses book for that year note visits to the works in Farringdon Street to see how they were progressing, visits which increased during the next year or so, for the teething troubles of power-driven aircraft which had never flown were just as many, and often worse for the pain they gave their designers, than those aircraft which are nowadays flying so high and fast that they can hardly be seen, although they can be very much heard.

Charles Spencer, who had experimented for a considerable time with a flapping wing machine, reached the stage early in 1872, when he thought he could successfully call upon the Society to help him with his experiments. Brearey, Glaisher and a Mr. Ashton visited Spencer in his works at Knightsbridge to discuss the machine, and paid a second visit before deciding the Society could not support Mr. Spencer, as his machine was unlikely to support him!

Much of the early part of the year, too, was spent by Wenham, Browning, Brearey and others with the experiments on inclined planes, and later in discussing a proposition with Wenham and Henry Coxwell for a method of altering the altitude of balloons by means of horizontal airscrews, as proposed by a non-member named Linfield.

A member, G. S. Hall, wanted the help of the Society to find him space to build his aerial machine. Save that Brearey went to the Crystal Palace to consult the authorities there about possible space, and a month later met Hall in the London Library, nothing further is known about the invention.

At the end of 1872 the balance in hand was £45 17s. 0d. and the membership 107.

The Eighth *Annual Report* was a bad start for the next seven years from the point of view of heavier-than-air craft enthusiasts.

Glaisher, in the Chair, characteristically, in opening the meeting, began with the words, "We meet again hopefully, as we have met on previous occasions . . . our progress has been for some years very slow indeed. Whether it has been much accelerated during the past year I cannot say, but still I think a decided improvement has been effected. It has been a year distinguished from previous years by experiments, and it is to experiments we must look for any ultimate success that may attend our efforts."

Glaisher, one of the greatest aeronauts of his time, referred with some enthusiasm to M. Dupuy de Lome's remarkable dirigible worked by man power. Glaisher spoke of the fact that the dirigible could be steered, and did not have to go with the wind, as a great achievement.

Just on fifty years afterwards, with all the knowledge which had been acquired of what a dirigible should be, J. C. Hunsaker, in his Wilbur Wright Memorial Lecture, "Naval Architecture in Aeronautics," read on 22nd June 1920, said of Dupuy de Lome's 1872 airship:

"This eminent architect attained by his professional skill the maximum success which the state of the mechanical art at that time permitted.

"His little hand-propelled Aerial Ship exhibited all the principal features of our modern non-rigids in their fundamental form. Control and stability were correctly understood and provided for. An airspeed meter was also provided. The requirements of our modern theory of suspending a car below a non-rigid gas bag were met by his suspension system. A ballonet and blower were used in accordance with good practice. More remarkable still Dupuy de Lome made the envelope of two-ply rubberised

fabric and doped it with a very fair gelatine, glycerine, acetic acid varnish to make it tight . . ."

The name of Dupuy de Lome deserves to be remembered not only as the leading architect of the day, but also as the first naval architect to apply his art to aeronautics.

The first paper at the Annual Meeting was from F. D. Artingstall of Manchester. It was read for him by the Hon. Secretary. Artingstall discussed the problem of hovering flight by birds and discussed it in such vague terms as the "angle of buoyancy" that Thomas Moy declared he thought few people would understand the paper. He further declared that he himself had found the true theory of flight. "On that subject I hope before another twelve months to be able to enlighten the Society, and to show that the true theory of flight has been found out and patented for more than a year."

To have patented the theory of flight, if such a patent would have been allowed, would have brought Moy the fortune he was always seeking to complete his experiments.

D. S. Brown, an active member of the Society who, in 1868 and 1869 had read papers on the power required for flight, read a paper on "The Aeroplane" embracing its Construction, Stability and means of Propulsion.

As the Society at the time this is being written is less than a decade from celebrating its hundredth birthday, and so a better assessment can be made of the lasting value of the ideas and work of early aeronautical pioneers, it is of interest to quote the opening words of D. S. Brown's lecture in June 1873:

"It is more than half a century since Sir George Cayley published the results of his researches in elucidation of the problem of Aerial Navigation by mechanical means, which was followed, several years afterwards, by the celebrated project of Mr. Henson, and since then has also appeared a valuable contribution by Mr. Wenham."

Brown drew attention to the absence of any steps to give the work of these three pioneers' ideas "a practical value." And added, "This is much to be regretted, as it represents so much time unnecessarily lost, and has probably delayed the realization of the most important means of locomotion for more than one generation."

But he stated his belief in man-power flight being possible with "two or three men working in a line," to reduce head resistance!

The members, however, were anxious to hear from Thomas Moy who, with his partner Richard Shill, was building a power-driven aeroplane. He and Shill were both sound practising engineers, and considerable attention was being paid to their experiments in consequence.

The two men had shown their engine to the Council at their meeting in April, and showed it again, working, at the Annual General meeting of members. It was stated at the Council meeting that the engine, inclusive of water and boiler, would not weigh more than 10 lb. per h.p. and at the Annual General Meeting that the average consumption was about six pints an hour. Moy declared that he could bring down the weight to 7 lb. per h.p. and that the engine he and Shill were making had been tested up to 500 lb. per sq. in. pressure, though the working pressure would not exceed 200 lb. per sq. in. He added that he and Shill were constructing an aerial machine, a working model with a lifting surface of some 60 sq. ft., powered with a 4 h.p. engine.

James Glaisher, who had been in close touch with the experiments, gave considerable praise to the new engine and boiler, pointing out that it was not a mere model. In fact it had been working for a year in Moy and Shill's workshop in London. In October it was arranged that a number of members of Council should have the opportunity of seeing the progress of the construction of what became known as Moy and Shill's Aerial Steamer. But final completion followed modern practice, so that the inevitable delays prevented the first trials being held until 1875.

Glaisher, closing the meeting, declared that he felt more struck with the Meeting than any other he had held before, and he hoped that when they met again they would be able to say they had progressed still more. Whatever else the small stalwart band of members did not possess, they certainly could not be accused of not possessing the fire of the pioneer in those days.

In the 1873 *Annual Report* was published a long paper by James Armour, C.E., under the title "Wings for Man." He was a member of the Institution of Civil Engineers and contributed other papers to the *Annual Reports* for 1874 and 1875.

This 1873 paper dealt with the theory of the lift of a series of planes arranged round the axis of a wheel, so that the chord line of each plane passed through a fixed point on the rim of the wheel. Armour argued that as the rotation of the wheel increased so did the lift on the planes as a whole and also the forward thrust. He laid down the general principle of construction of such a machine and gave specimen calculations of the lift and thrust of a wing as it revolved round the wheel axis. He stated that his paper was purely a discussion on the possibilities of such a machine, going forward on a straight course only. He drew attention to the point that if the engine stopped while the machine was in flight, the wings would continue to rotate and so enable a descent to be made. Various arrangements of the planes were considered, so that they could all be placed at the same angle of attack for gliding purposes.

At the end of the paper Armour considered the motion of a bird's wing and how, from that motion, both lift and thrust were obtained.

Brearey made no note of the balance in hand at the end of 1873 but the Council Minutes of 20th March 1874 noted that there was £32 0s. 0d. in the kitty, and the membership 115, of whom 83 had paid their subscriptions.

REFERENCES

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TECHNICAL NOTES

An Observation on the use of Dimensional Analysis and Similarity Relations in Non-Uniform Heat Transfer

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INTRODUCTION

The theoretical study of heat transfer in ducts and passages which are not circular is difficult. In addition to geometrical and hydrodynamic problems, thermal aspects such as non-uniformity of heat transfer at the section boundary, increase the number of variables to be taken into account. The popular and perhaps simplest technique for the prediction of heat transfer in forced turbulent convection in non-circular ducts, is to use the more easily determined equation for an equivalent circular section. The form of the equation, which is used to correlate experimental data for the simpler case of heat transfer in the circular section, may be derived from considerations of similarity or alternatively by dimensional analysis. (Reference may be made to the classical work of W. Nusselt at the early part of the present century for the derivation of such an equation.) The equivalent circular pipe is equivalent in two respects. It is a pipe which has the same pressure drop and same heat transfer as the non-circular duct under consideration for the same conditions. The diameter of the equivalent pipe which replaces the non-circular section will be discussed later.

There is no doubt that the procedure outlined is satisfactory in a large number of cases of heat transfer in turbulent flow in non-circular sections. Despite the fact that experimentation with these sections is more difficult and less reliable, the equivalent pipe method has been used without question in annuli, rectangular channels and other miscellaneous shapes. Experiment is an essential part of dimensional analysis, and in many cases the experimentally determined numerical constants for pipe flow have been used in the equivalent pipe method for the non-circular sections. Any deficiency of this technique is not readily apparent and the divergencies between experiment and theory have usually been attributed to experimental error. It is possible that in many of these cases the method is only approximate. The form of the pipe equation is derived by considering the variables which enter into the problem. When applied to a non-circular section through the concept of equivalent diameter, the equation might not take cognizance of all the variables because additional factors such as that of non-uniform heat transfer have been imported. The agreement between the equivalent pipe equation and the experimental data for the non-circular section might be fortuitous. On the other hand, it is possible that the additional variables (as in the case of non-uniform heating) are of secondary importance.

Much of the literature on heat transfer in non-circular sections offers no justification for the use of the equivalent diameter method in cases where the heat flux distribution around the section is variable. The purpose of this note is to consider non-uniform heat transfer from the dimensional analysis and similarity aspects. While a solution to the general problem by these methods is not proposed, a limitation of the accepted method used in the prediction of non-uniform heat is discussed.

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DIMENSIONAL ANALYSIS CONSIDERATIONS

The prediction of heat transfer in forced turbulent convection by the method of dimensional analysis is well known. The conventional approach to the problem will be outlined briefly.

Consider a fluid in steady incompressible turbulent flow near a heated boundary (such as a pipe wall or flat plate) as shown in Fig. 1. The heat transfer to the fluid is by conduction through a fictitious laminar flow film adjacent to the boundary and then by turbulent mixing in the main flow. The variables affecting the heat flux q at the boundary are the geometry and size of the boundary, the fluid properties viscosity, μ, thermal conductivity, K, specific heat, c, and density ρ. In addition, the velocity of the fluid u, which affects the laminar film thickness and a temperature difference ΔT which is the driving force for heat flow, must be included. The temperature difference is the difference between the wall temperature and the fluid temperature which in the case of a closed conduit is most conveniently taken as the mixed mean or bulk temperature.

For a very long pipe where the diameter d is a characteristic of the geometry, we may write

$$q = F(u,\ d,\ \Delta T,\ c,\ \mu,\ K,\ \rho)$$

which in the usual way results in

$$\frac{q}{\Delta T}\frac{d}{K} = F\left(\frac{ud\rho}{\mu},\ \frac{c\mu}{K}\right)$$

or

$$Nu = F(Re,\ Pr) \quad . \quad . \quad . \quad (1)$$

where Nu, Re, Pr are the Nusselt, Reynolds and Prandtl numbers respectively.

By definition, $(q/\Delta T) = h$ where h is described as the convective or film heat transfer coefficient.

The most common form of equation (1) is

$$Nu = A\,(Re^{m})\,(Pr^{n}) \quad . \quad . \quad . \quad (2)$$

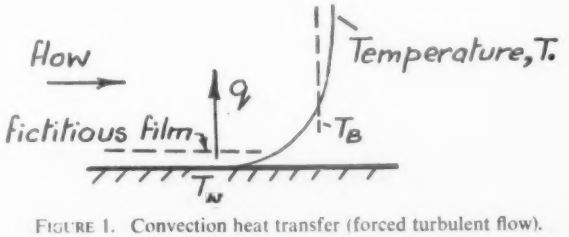

FIGURE 1. Convection heat transfer (forced turbulent flow).

where A, m and n are determined experimentally. This type of equation has proved entirely satisfactory in pipe flow where experiment is relatively straightforward. Allowance for variable fluid properties may be accounted for by simple modifications.

In this work, we are concerned with non-uniform heat transfer which usually occurs in a non-circular section. One solution is to use the previous result, *i.e.* equation (2), with the equivalent diameter of the section as the characteristic dimension in the Nu, Re and Pr parameters. The equivalent diameter of a non-circular section is deduced from considerations of flow. The Reynolds number is a measure of the relative importance of inertia and viscous forces, *i.e.* it is a ratio of inertia force to viscous force. These forces are proportional to the flow across section A and the perimeter P respectively, and the equivalent diameter of a non-circular section is $4 \times A/P$ (the 4 arises from the condition that the equivalent diameter and the ordinary diameter of a pipe are the same thing when $(4 \times \pi d^2/4)/(\pi d) = d$). The derivation of the equivalent diameter has been deduced from equivalence of flow and is also used in the heat transfer study. Alternative definitions exist in heat transfer but these are not considered here.

The use of equation (2) (with the equivalent diameter and the values of A, m, n for pipe flow) in cases of non-uniform heat transfer is questionable. Consider an example of heating a fluid between two parallel boundaries as shown in Fig. 2. In general the heat fluxes q, q', are different. Common sense reasoning indicates that the heat flux q' at one wall is not independent of the temperature difference ΔT for the opposite wall where the heat flux is q. It appears that the list of variables given previously for uniform heating is incomplete when it is desired to determine the heat transfer coefficient h for the q wall. It is possible that an equation of the form $Nu = ARe^m Pr^n$ might be satisfactory for the determination of heat transfer coefficients in non-uniform heating, but the new values of A, m and n would be valid only for a given (q'/q) ratio. When using this form of equation in geometrically similar non-circular sections, we suggest that the added restriction of $(q'/q) = \text{constant}$ must be imposed. This statement is supported by the results of similarity considerations which are presented later. The careless use of $Nu = ARe^m Pr^n$ in non-uniform heating might lead to serious error when the heat flux distribution is a significant factor. The inclusion of simple variations in heat flux around a closed conduit in semi-theoretical analysis, which use analogies between heat transfer and fluid momentum, is possible. This approach shows that the heat transfer coefficient on one wall is dependent on the distribution of heat flux around the whole boundary. The results of dimensional analysis cannot be expected to show this dependency unless it is recognised and included by a suitable choice of variables at the outset.

How this additional factor could be allowed for in the dimensional analysis study is not considered here.

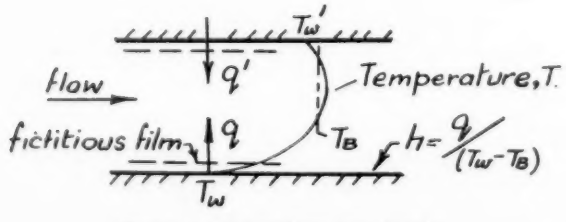

FIGURE 2. Non-uniform heat transfer.

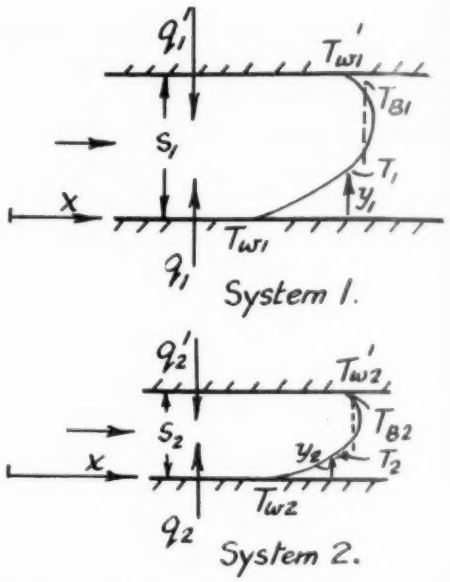

FIGURE 3. Similar systems in non-uniform heat transfer.

SIMILARITY CONSIDERATIONS OF NON-UNIFORM HEAT TRANSFER

The results of similarity considerations of non-uniform heat transfer support the conclusions made in the previous section. The method is identical to the standard approach and will be presented here in a somewhat abbreviated form. A particular case of non-uniform heat transfer will be considered because it permits simple explanation and analysis.

Consider two geometrically similar systems (suffices 1 and 2) as shown in Fig. 3. The system consists of two plane parallel walls between which fluid flows in steady incompressible turbulent flow. The heat fluxes at the walls are q and q'. It is proposed to study the conditions under which the systems are hydrodynamically and thermally similar. For hydrodynamic similarity it is necessary that the Reynolds number $\{u(2s)\rho\}/\mu$ should be the same in both cases. This requirement is easily shown from the fluid motion equations for a real fluid and elaboration is unnecessary.

The low speed steady flow energy equation which is applicable here is

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} - \frac{u}{\rho c}\frac{\partial p}{\partial x} = \frac{K}{\rho c} \times \frac{\partial^2 T}{\partial y^2}$$

(where p is pressure)

and this may be used to show that thermal similarity requires

$$Pr_1 = Pr_2 \text{ where } Pr = (c\mu/K).$$

In addition, we must consider the heat transfer coefficient which is defined as

$$h = \frac{q}{\Delta T} = \frac{-K(\partial T/\partial y)_{\text{wall}}}{\Delta T}$$

ΔT in this case is equal to $(T_w - T_B)$.

The two systems are related in the following way.

$$h_2 = A(h_1) \text{ and } h_2' = A(h_1')$$

$y_2 = B(y_1)$ when $B = (S_2/S_1)$

$T_2 - T_{B2} = C(T_1 - T_{B1})$

and $K_2 = D(K_1)$ $\mu_2 = E(\mu_1)$ $c_2 = F(c_1)$ $\rho_2 = G(\rho_1)$

where A, B, C, D, E, F, G are similarly constants.

For the lower boundaries,

$$q_1 = -K_1\left(\frac{\partial T_1}{\partial y_1}\right)_{\text{wall}} = h_1(T_{w1} - T_{B1}) \quad . \quad (3)$$

and

$$q_2 = -K_2\left(\frac{\partial T_2}{\partial y_2}\right)_{\text{wall}} = h_2(T_{w2} - T_{B2}) \quad . \quad (4)$$

Substituting the similarity relationships in (4)

$$\frac{q_2}{AC} = -\left(\frac{D}{AB}\right)K_1\left(\frac{\partial T_1}{\partial y_1}\right)_{\text{wall}} = h_1(T_{w1} - T_{B1}).$$

For the upper walls, similar relationships exist. These are

$$q_1' = +K_1\left(\frac{\partial T_1}{\partial y_1}\right)_{\text{wall}} = h_1'(T_{w1}' - T_{B1}) \quad . \quad (5)$$

and

$$\frac{q_2'}{AC} = +K_1\frac{D}{BA}\left(\frac{\partial T_1}{\partial y_1}\right)_{\text{wall}} = h_1'(T_{w1}' - T_{B1}) \quad (6)$$

For similarity between the two systems, as far as heat transfer on the lower wall is concerned, equations (3) and (4) insist on (D/AB) being equal to unity, or

$$\frac{h_1(2S_1)}{K_1} = \frac{h_2(2S_2)}{K_2} \qquad (Nu_1 = Nu_2)$$

which is the usual Nusselt relationship, and

$$\frac{q_2}{q_1} = (AC).$$

From equations (5) and (6), since $(D/AB) = 1$, $\frac{q_2'}{q_1'}$ also equals (AC).

Therefore, it follows that if the three parameters Nu, Re and Pr are used to correlate forced turbulent convection data in non-uniform heat transfer, the local heat flux ratios around the boundaries must bear a constant ratio to each other.

If an equation of the form

$$Nu = ARe^m Pr^n$$

is used for a given variation of heat flux, strictly speaking, the values of A, m and n are only valid for that particular heat flux distribution. In going from one case to another, we must insist on a constant heat flux ratio, if Nu, Re, Pr are the only significant parameters.

CONCLUSION

In this note we have studied dimensional analysis and similarity relations for heat transfer which is not uniform around a flow boundary. Ventilation and cooling in nuclear power installations are two examples in this field of work which are readily called to mind. The main purpose of the present note is to show the limitations of well established equations which are sometimes used to predict heat transfer in these cases. It appears that these equations are used in such instances without the implications being realised. By chance, the methods used are often satisfactory but the justifications of the use of these methods are not always found in the literature.

Thermal Bending of a Tri-Metal Strip

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THE GENERAL ELASTIC ANALYSIS of the bending of a bi-metallic strip subjected to uniform heating has been made by Timoshenko[1]. In this note we extend the theory to that of a tri-metal strip. General formulae for curvature and bending stresses have been developed. These formulae reduce to simple expressions if a particular choice of material constants and thicknesses is made. These latter formulae indicate that the curvature can be independent of the coefficient of linear expansion of the middle material and that it is possible to have the stresses at the inter-surfaces equal if a proper choice of the ratios of the coefficients of linear expansion of the three materials is made.

An elastic-plastic analysis of the bi-metal strip has recently been made by Mahrenholtz and Johnson[2].

NOTATION

h total thickness of strip
a_1, a_2, a_3 thickness of each material
$\alpha_1, \alpha_2, \alpha_3$ coefficients of linear expansion of the materials $(\alpha_1 > \alpha_2 > \alpha_3)$
E_1, E_2, E_3 Moduli of elasticity of the materials
I_1, I_2, I_3 second moments of area of the materials
ΔT rise in temperature of the strip due to uniform heating
ρ the radius of curvature of the strip due to bending
$K_1 = (\alpha_1 - \alpha_2)/(\alpha_1 - \alpha_3)$
$K_2 = (\alpha_2 - \alpha_3)/(\alpha_1 - \alpha_3)$
$S_1 = a_1E_1$, $S_2 = a_2E_2$ and $S_3 = a_3E_3$.

1. ANALYSIS

The strip is made of three different materials firmly welded together at their common interfaces and is as shown in Fig. 1(*a*) and (*b*). Due to a rise in temperature the strip bends as shown in Fig. 1(*c*) convex upwards. It is assumed that plane sections remain plane when bending occurs and analysis is made for unit width of the strip.

Consider a length of the strip cut by sections AA and BB. The forces acting on each metal can be represented by an axial force and moment as shown in Fig. 1(*c*). Then for equilibrium, we have:

$$P_1 + P_2 + P_3 = 0 \quad . \quad . \quad . \quad (1)$$

$$M_1 + M_2 + M_3 - \frac{P_1a_1}{2} - P_2\left(a_1 + \frac{a_2}{2}\right) - P_3\left(a_1 + a_2 + \frac{a_3}{2}\right) = 0 \quad . \quad . \quad (2)$$

$$\frac{1}{\rho} = \frac{M_1}{E_1I_1} = \frac{M_2}{E_2I_2} = \frac{M_3}{E_3I_3} = \frac{\Sigma M}{\Sigma EI} \quad . \quad (3)$$

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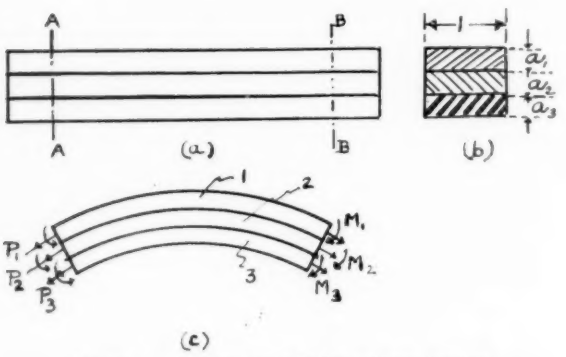

FIGURE 1. Tri-metal strip under uniform heating.

Consideration of the equality of intersurface strains at each interface lead to

$$\alpha_1\Delta T + \frac{P_1}{a_1E_1} - \frac{a_1}{2\rho} = \alpha_2\Delta T + \frac{P_2}{a_2E_2} + \frac{a_2}{2\rho} \quad . \qquad (4)$$

$$\alpha_2\Delta T + \frac{P_2}{a_2E_2} - \frac{a_2}{2\rho} = \alpha_3\Delta T + \frac{P_3}{a_3E_3} + \frac{a_3}{2\rho} \quad . \qquad (5)$$

These five equations can be re-arranged as follows:

$$P_1 + P_2 + P_3 + \frac{1}{2\rho}(0) = 0$$

$$P_1S_2 - P_2S_1 + P_3(0) + \frac{1}{2\rho}\{-S_1S_2(a_1+a_2)\} = (\alpha_2-\alpha_1)\Delta T.S_1S_2$$

$$P_1(0) + P_2S_3 - P_3S_2 + \frac{1}{2\rho}\{-S_2S_3(a_2+a_3)\} = (\alpha_3-\alpha_2)\Delta T.S_2S_3$$

$$P_1l_1 + P_2l_2 + P_3(0) + \frac{1}{2\rho}[2\Sigma EI] = 0$$

where $l_1 = \dfrac{a_1+2a_2+a_3}{2}$ and $l_2 = \dfrac{a_2+a_3}{2}$

Hence
$$\frac{1}{2\rho} = \frac{\begin{bmatrix} 1 & 1 & 1 & 0 \\ S_2 & -S_1 & 0 & (\alpha_2-\alpha_1)\Delta T.S_1S_2 \\ 0 & S_3 & -S_2 & (\alpha_3-\alpha_2)\Delta T.S_2S_3 \\ l_1 & l_2 & 0 & 0 \end{bmatrix}}{\begin{bmatrix} 1 & 1 & 1 & 0 \\ S_2 & -S_1 & 0 & -S_1S_2(a_1+a_2) \\ 0 & S_3 & -S_2 & -S_2S_3(a_2+a_3) \\ l_1 & l_2 & 0 & 2\Sigma EI \end{bmatrix}}$$

i.e.
$$\frac{1}{2\rho} = \frac{\begin{bmatrix} 1 & 1 & 1 & 0 \\ S_2 & -S_1 & 0 & \dfrac{(\alpha_2-\alpha_1)}{S_3} \\ 0 & S_3 & -S_2 & \dfrac{(\alpha_3-\alpha_2)}{S_1} \\ l_1 & l_2 & 0 & 0 \end{bmatrix}}{\begin{bmatrix} 1 & 1 & 1 & 0 \\ S_2 & -S_1 & 0 & \dfrac{-(a_1+a_2)}{S_3} \\ 0 & S_3 & -S_2 & \dfrac{-(a_2+a_3)}{S_1} \\ l_1 & l_2 & 0 & \dfrac{2\Sigma EI}{S_1S_2S_3} \end{bmatrix}} \Delta T.S_1S_2S_3$$

Hence,
$$\frac{1}{2\rho} = \Delta T \cdot \frac{A}{B}$$

where
$$A = \begin{bmatrix} 1 & 1 & 1 & 0 \\ S_2 & -S_1 & 0 & \dfrac{\alpha_2-\alpha_1}{S_3} \\ 0 & S_3 & -S_2 & \dfrac{\alpha_3-\alpha_2}{S_1} \\ l_1 & l_2 & 0 & 0 \end{bmatrix}$$

and
$$B = \begin{bmatrix} 1 & 1 & 1 & 0 \\ S_2 & -S_1 & 0 & \dfrac{-(a_1+a_2)}{S_3} \\ 0 & S_3 & -S_2 & \dfrac{-(a_2+a_3)}{S_1} \\ l_1 & l_2 & 0 & \dfrac{2\Sigma EI}{S_1S_2S_3} \end{bmatrix}$$

Evaluating the determinants:

$$\frac{1}{\rho} = \frac{2\Delta T\left[\dfrac{(\alpha_1-\alpha_2)(a_1+a_2)}{S_3} + \dfrac{(\alpha_2-\alpha_3)(a_2+a_3)}{S_1} + \dfrac{(\alpha_1-\alpha_3)(a_1+2a_2+a_3)}{S_2}\right]}{\dfrac{(a_1+a_2)^2}{S_3} + \dfrac{(a_2+a_3)^2}{S_1} + \dfrac{(a_1+2a_2+a_3)^2}{S_2} + \dfrac{4\Sigma EI\Sigma S}{S_1S_2S_3}} \quad . \quad . \qquad (6)$$

Similarly P_1, P_2 and P_3 can be determined as follows:

$$P_1 = -\frac{S_1S_2\left[(\alpha_1-\alpha_2)\Delta T - \dfrac{a_1+a_2}{2\rho}\right] + S_1S_3\left[(\alpha_1-\alpha_3)\Delta T - \dfrac{a_1+2a_2+a_3}{2\rho}\right]}{S_1+S_2+S_3} \quad . \quad . \qquad (7)$$

$$P_2 = \frac{S_1S_2\left[(\alpha_1-\alpha_2)\Delta T - \dfrac{a_1+a_2}{2\rho}\right] - S_2S_3\left[(\alpha_2-\alpha_3)\Delta T - \dfrac{a_2+a_3}{2\rho}\right]}{S_1+S_2+S_3} \quad . \quad . \qquad (8)$$

$$P_3 = \frac{S_1S_3\left[(\alpha_1-\alpha_3)\Delta T - \dfrac{a_1+2a_2+a_3}{2\rho}\right] + S_2S_3\left[(\alpha_2-\alpha_3)\Delta T - \dfrac{a_2+a_3}{2\rho}\right]}{S_1+S_2+S_3} \quad . \quad . \qquad (9)$$

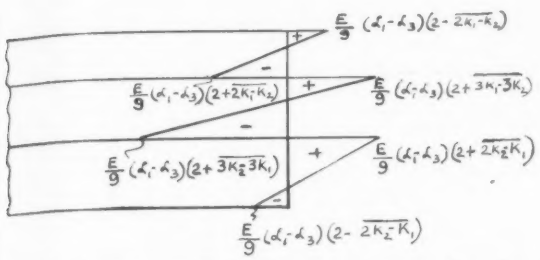

FIGURE 2. Normal stress distribution on any cross section of a tri-metal strip under uniform heating for unit rise in temperature.

2. A SPECIAL CASE

It is possible to choose three materials having different coefficients of linear expansion but of very nearly equal Moduli of Elasticity. In such a case no great error will be introduced by taking

$$E=\frac{E_1+E_2+E_3}{3}$$

$$=E_1=E_2=E_3.$$

Assuming $a_1=a_2=a_3$, for unit rise in temperature we find:

$$\frac{1}{\rho}=\frac{4}{3h}(\alpha_1-\alpha_3) \quad . \quad . \quad . \quad . \quad (10)$$

$$P_1=-\frac{Eh}{27}(\alpha_1-\alpha_3)(2K_1-K_2) \quad . \quad (11)$$

$$P_2=\frac{Eh}{27}(\alpha_1-\alpha_3)(3K_1-3K_2) \quad . \quad . \quad (12)$$

and

$$P_3=\frac{Eh}{27}(\alpha_1-\alpha_3)(2K_2-K_1) \quad . \quad . \quad (13)$$

The stress distribution for this simplified case is as shown in Fig. 2. The bending stress in each case is equal to $\pm\frac{E}{\rho}\cdot\frac{a}{2}=\pm\frac{2E}{9}(\alpha_1-\alpha_3)$ and the direct stresses $\frac{P_1}{a_1}$, $\frac{P_2}{a_2}$ and $\frac{P_3}{a_3}$. It can easily be shown that the sum of the stresses distributed over the entire cross section is zero. It is obvious that by choosing values of α_1, α_2 and α_3 so that $\frac{K_1}{K_2}$ varies from $\frac{1}{2}$ to 2 the stresses in the three materials can be varied. Particularly if $K_1=K_2$ the inter-surface stresses are equal.

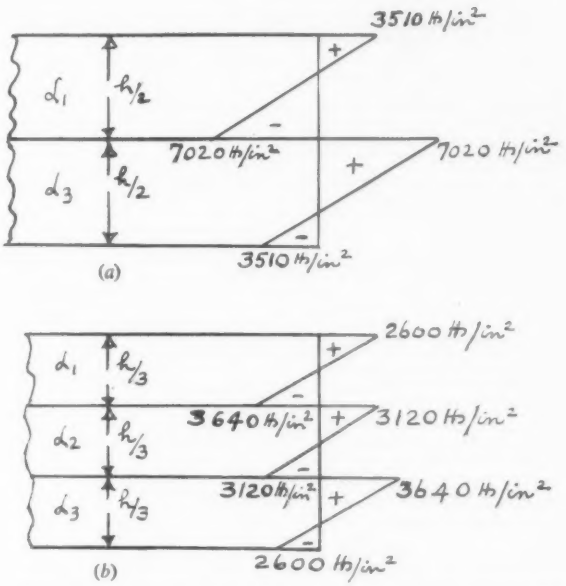

FIGURE 3. Normal stress distribution on any cross section due to uniform heating for two special cases.

3. NUMERICAL EXAMPLE

Two examples are chosen to illustrate the results of the simplified case:

Case I

$$\alpha_1-\alpha_3=6\times10^{-6} \text{ per } ^\circ\text{C}, \quad E=27\times10^6 \text{ lb./in.}^2,$$
$$K_1=\tfrac{1}{3} \text{ and } K_2=\tfrac{2}{3}$$

The stress distribution is shown in Fig. 3(*a*).

Case II

$$\alpha_1-\alpha_3=4\times10^{-6} \text{ per } ^\circ\text{C}, \quad E=27\times10^6 \text{ lb./in.}^2,$$
$$\text{and } K_1=K_2=\tfrac{1}{3}$$

The stress distribution is shown in Fig. 3(*b*).

In both cases the stress distributions are for 1°C. rise in temperature and values were obtained using equations (10), (11), (12) and (13).

REFERENCE

1. S. TIMOSHENKO (1925). Analysis of Bi-Metal Thermostats. *Journal of the Optical Society of America.* Vol. II, 1925.
2. O. MAHRENHOLTZ and W. JOHNSON. On Bimetal Thermostats. *Inter. J. Mech. Sci.* (*to be published*).

THE BRANCHES

Beginning in 1944 *as* BIRMINGHAM, 1959 *saw the Branch change to* BIRMINGHAM *and* WOLVERHAMPTON.

The credit for the suggestion of a Birmingham Branch must undoubtedly be ascribed to Mr. A. G. Stawford, A.R.Ae.S., who was to become the first Secretary and is today the Treasurer.

The inaugural Meeting was held in 1944, following a notice in the Society's JOURNAL and the local press, by Mr. Stawford. The Meeting was well attended and overflowed the room, proof of the necessity for and interest in a Branch. This was approved by the Society in November 1944 and by the end of the year the membership was 325.

Support came mainly from The Austin Motor Co. Aircraft Factory and the Castle Bromwich Aircraft Factory, bombers being made at Austin and Spitfires at Castle Bromwich. There were also many sub-contractors manufacturing components or complete assemblies, and Joseph Lucas Ltd. were producing more Spitfire wings than any other factory, as well as pioneering the Combustion and Fuel System for the Gas Turbine. Thus Birmingham was very much an aircraft centre, but after the war, both the Austin and Castle Bromwich factories closed, leaving a very tough job for the Branch Committee to keep going. This problem was met by holding some lectures in Wolverhampton where Boulton Paul Aircraft Ltd. and H. M. Hobson Ltd. are situated.

If we may jump the years to 1959, it was following the A.G.M. of that year that the Branch became BIRMINGHAM and WOLVERHAMPTON in recognition of the excellent support given by the Wolverhampton members. For a number of years at least one, and occasionally two, lectures had been held at Wolverhampton, but from 1959 all lectures, Committee meetings and the A.G.M. alternate between the two. This arrangement has been a great success.

The initial lecture in 1944 was given by the first Branch President, the late Capt. Nicolson, F.R.Ae.S., on the Evolution of the Modern Aircraft. This was followed by a lecture on the trend of Aircraft Design by Prof. S. C. Redshaw, F.R.Ae.S., who is a Past-President of the Branch.

In April 1945 an interesting experiment was tried in forming a Brains Trust, the Chairman acting as Question Master and the Committee as the Panel. This proved so successful that it has been repeated on many occasions.

A novel evening was arranged in 1946 when a Panel was formed of Sir Frederick Handley Page, C.B.E. (then President, R.Ae.S.), the Lord Mayor of Birmingham, Mr. R. H. Bound, F.R.Ae.S. (Branch President), Mr. J. D. North, F.R.Ae.S. (Director, Boulton Paul Aircraft), Captain I. D. Nicolson, F.R.Ae.S. (representing the Shipping concerns), Mr. C. Raynor Smith (Asst. Dist. Superintendent G.W.R.), Mr. J. Silverman, M.P., Mr. L. Gupwell (Vice-President, Institute of Transport) and the subject was the Future of Air Transport and the extent to which it might supplement or supersede surface travel. The minutes of the Meeting make interesting reading today, and the pattern of air travel in the Birmingham area has followed closely some of the proposals made. The Society can, therefore, claim to have some influence in this area.

A notable lecture given in 1947 by Lord Brabazon had a good report in the local press, the *Birmingham Mail* reporting Lord Brabazon as saying "That a good point in favour of the Gas Turbine Engine is that the use of fuel oil (paraffin?) eliminates the risk of fire from highly inflammable petrol." The subject now covers the international press, and in the same general context Lord Brabazon continues to make the point.

The first Main Lecture given outside London at a Branch was given by Dr. E. W. Still, then of Rolls-Royce, on "Operation of Aircraft under Low Temperature Conditions," in 1949. This was the start of the successful series of Main Lectures held at the Branches. The Branch has had many firsts and perhaps the one of most historical interest is connected with the Presidential Chain of Office. The first occasion when this was worn in Public was at the Annual Dinner of the Branch in 1947 when Sir Harold Roxbee Cox was the Society President.

A feature of the lecture year has been the President's Night, first introduced in 1953. The President on this night selects the form of Lecture and always ensures that it has a great interest to the Ladies who are invited to attend: perhaps the most notable evening was in 1959 when the President, Mr. F. F. Crocombe, F.R.Ae.S., gave a lecture on his experiences of 30 years in the Aircraft Industry.

The Branch has organised many visits to places of aeronautical interest and these have always been well attended, the only regret is that a visit to the Shuttleworth Collection has not been possible although it is so near. Perhaps Air Commodore Wheeler would consider changing the time of opening of the Trust, provided, of course, that the Aircraft Industry in these parts would not give all R.Ae.S. members the day off to get back to first principles.

One first principle is that of Man Powered Flight, a subject of keen interest to the Members. In 1949 Capt. Pritchard gave his paper on Bird Flight, and in 1960 a paper was given by Mr. Nayler on "Man Powered Flight," both subjects attracting a large audience. Any day now, a third lecture could be of current interest.

Of men and interest in Flight, the Branch ask that mention be made of C. P. Holmes, who as Secretary ran the Branch so successfully from 1945-1955 when he departed to Southern Rhodesia, and of Dr. C. S. Greenland, now serving his third year as President. Finally, to mention all, the membership is 106, of whom 44 are Main Society Members.—G.W-W.

The Branch representatives who attended the Third Branches Conference at Preston on 13th May 1961, photographed at St. Anne's-on-Sea. In the centre, Miss Croad, Dr. A. M. Ballantyne and Sir Owen Jones, the President.

Graduates' and Students' Section

Report on the Section Visit to the Paris Air Show

The instruction sheet informed members that the Hon. International Visits Secretary could be identified by his black beard. However, on arrival at the Victoria Coach Station on the afternoon of Friday, 2nd June, members of the Sections' party were confronted by seven people fitting this description. *Sic transit gloria.* Members can rest assured that Mr. Hampton did not have the air of a man being hunted by Interpol, nor was he observed removing his beard at any stage of the trip.

Having completed the usual formalities, the party departed at 3.30 p.m. for a coach ride through the pleasant Kent country-side to Lympne airfield. After passing through Customs there was a delay of about ten minutes while an engine fault was corrected on the Skyways Ltd. DC-3. One hour later the aircraft landed at Beauvais and we finally arrived at our hotel in Paris at 9.0 p.m. At least, we thought that it was our hotel but we discovered that only eleven of the party were to stay there, the others entered the foyer of an adjacent hotel—only to be directed to a third hotel where they were greeted in the usual French style, but after about ten minutes they discovered that they were, after all, expected and that 25 beds were available. Both hotels proved to be clean and comfortable and were situated near Place de Clichy in Montmarte.

Once base was established, the party split into small groups and little was seen of the others until 5.15 p.m. on the Sunday. The stories of the experiences during our 44-hour stay in the French Capital would fill this page for several months. The case of the British electric razor versus the French electricity supply ended with honours even—the razor owner borrowing a safety razor and the hotel calling in the electricians.

The majority of the party took the opportunity of inspecting the many varied and interesting aircraft that were on show at Le Bourget. The airport is normally about a 20 minute ride from Montmartre, but on the Saturday, a party who had hired a car for the day found that the journey took two hours. Several others took taxis but found that it was quicker and much cheaper to walk, when the traffic was jammed in five lanes about a mile from the airport. Most people returned by train!

The weather was fine throughout our stay. A light cloud coverage kept the temperature within comfortable limits but did not curtail the flying display, although some localisation was necessary for maximum visibility.

Most of the party endeavoured to see more of the Parisiennes, in one way or another, on the Saturday evening. On Sunday, some people revisited the Air Show, but most of the members spent their time visiting museums, art galleries and other places of interest. All too soon our stay was over and reclining seats in our French coach were put to full use on the return journey to Beauvais, in an attempt to recover a little lost sleep.

The Skyways schedule allowed time for people to buy duty-free goods at the airport. The return flight was very smooth and the views from our cruising altitude of 2,500 ft. were beautiful indeed. Having satisfied the Customs that we were not large scale importers, we set off for London. Heavy traffic caused some delay so it was a tired but happy party that reached Victoria about 30 minutes after E.T.A.

The thanks of all those who went on this visit go to the Hon. International Visits Secretary, Mr. Peter Hampton, who put in a great deal of work to ensure that everything ran smoothly and efficiently.

The Committee hope that this visit will be repeated in 1963 but it is only possible to organise such visits with the full support of members. Early bookings are necessary to secure desired travel times, and deposits are forfeited at a fairly early date. At one stage it appeared that the 1961 visit would have to be cancelled due to lack of support, in fact, of the party which visited Paris, only about 50 per cent were Graduates and Students. The party were unanimous in agreeing that the visit was good fun, full of interest and gave excellent value for money. On this last point it should be mentioned that the sum of £1 was returned to each member of the party following the payment of all costs, and members were thus able to enjoy this visit for only nine guineas.—J.D.B.

New Committee 1961-62—Officers

The office holders for the year are as follows:

Chairman: **W. G. Wilson** (Graduate), de Havilland Aircraft Co. Ltd.

Hon. Secretary and Deputy Chairman: **H. Frazer Mitchell** (Graduate), Handley Page Ltd.

Hon. Visits Secretary: **N. R. Craddock** (Graduate), Handley Page Ltd.

Hon. Treasurer: **J. F. Wilby** (Graduate), de Havilland Aircraft Co. Ltd.

Hon. Editor: **P. Hampton** (Graduate), Royal Aircraft Establishment, Farnborough.

Awards for Section Members

It is a source of considerable disappointment to the members of the Section Committee that the Council of the Society were unable to award the Pilcher Memorial Prize this year. The reason for this is a sad commentary on the enthusiasm of members, and results from the fact that there were no entries. This award is made at the discretion of the Council for the most valuable paper read by a member of the Graduates' and Students' Section before any meeting of the Society, and it is surprising that from a membership in excess of three thousand the Section was unable to muster one entrant. We hope to publish details of all the awards open to members later this year to encourage participation.

A view of the 24th International Air Show, Le Bourget (26th May-4th June), which was visited by a party of Section members.

THE LIBRARY

Reviews

SCIENCE AND GOVERNMENT. *C. P. Snow. Oxford University Press*, 1961. 88 *pp.* 9*s.* 6*d.*

This book contains the text of the Godkin Lectures delivered by the author at Harvard in 1960. An American commentator has said of Sir Charles Snow that he "has the intellect of a professor; the confidence of a soothsayer; the erudition of a top-flight statesman; the devil-may-care approval of a warm-blooded novelist; and the hard shell technique of a successful business man," and added, for good measure, "His progress through the inner sanctums of Britain's Establishment is noted for its punctuation by the explosion of literary atom bombs."

This book is a literary bomb shell indeed. It has already raised a Snow storm in England and America and may well become a controversial fall out between Governments and Scientists. It is a book to read whether you are a Civil Servant, a scientist, or just a human nutrino. For not to have read it will be a confession that the future does not interest you. After all it is the only time in which you have got to live.

On page 4 the author writes, "This book is about two men and two choices. The first of the two men is Sir Henry Tizard. Let me declare my interest straight away . . . I believe, along with a number of Englishmen who are interested in recent military-scientific history, that Tizard's was the best scientific mind that in England has ever applied itself to war. I further believe . . . that of all the people who had a share in England's surviving the air battles of July to September 1940, Tizard made a contribution at least as great as any. It has not yet been properly recognised."

This is not a book which can be reviewed without prejudice, and I therefore declare that I am prejudiced on the side of Tizard, for I had much to do with him when he was a member of Council of the Royal Aeronautical Society, and its Chairman during a year of great difficulty in its history. My prejudice is not only because I agree so much with his friend Sir Frederick Brundett, who wrote on Tizard's death, "He was well endowed with scientific foresight as any one"; but because I have owed him a tremendous debt of gratitude for over thirty-five years for giving me the opportunity, which every man desires, to do the job which gives him the greatest happiness and satisfaction.

The other man was Professor Lindemann (Lord Cherwell), who became the friend of Sir Winston Churchill, and his scientific adviser during much of the war with Hitler.

In 1935 Tizard was appointed Chairman of a Committee for the Scientific Study of Air Defence, at the suggestion of H. E. Wimperis, Scientific Adviser to the Air Ministry.

"By the end of 1935 its important decisions were in effect taken. By the end of 1936 most of these decisions were translated into action. It was one of the most effective small committees in history," writes Snow.

"The issue in principle was very simple," he added. "Radar was not yet proved to work; but Tizard and the others were certain it was the only hope . . . Therefore the first priority must be given to radar . . . Lindemann would not have any of this. Radar was not proved. He demanded that it should be put much lower on the priority list and research on other devices given the highest priority."

This was the issue which made Snow write, "This is about two men and two choices." It is in consequence an explosive theme, and is not to be told fairly in a review. For it appears certain that no one who has known the two principals of the story can give an unbiassed account.

Tizard was for some time a member of Council of the Royal Aeronautical Society, at a time when I was on the Council. He became its Chairman, and the Chairman of the Aeronautical Research Council. Aeronautics owes him a tremendous and unpaid debt.

In 1924 he lectured to the Society on Commonsense and Aeronautics and began, "It is perhaps a provocative title; it might even lead the unkind to believe that the lecturer was claiming the monopoly of a commonsense point of view. I make no such absurd pretension; I am using the word in what I take to be its literal meaning, namely the intelligent thoughts of the ordinary man."

In his diary Tizard wrote, on May 8th, 1945, "I wonder if the part that scientists have played will ever be faithfully and fully recorded. Probably not."

I have said the book is explosive in its content, but its importance lies in the conclusions which the author draws of the relationship between the scientist and the politician.

"I think most of us would agree that it is dangerous to have a solitary scientific overlord. It is specially dangerous to have him sitting in power, with no scientist near him . . ."

But the author is just as certain that it is of fundamental importance to have scientists in the Government at all levels.

"Scientists have it within them to know what a future-directed society feels like, for science itself, in its human aspect, is just that . . . We are immensely competent; we know our own pattern of operations like the palms of our hands. It is not enough . . . It would be bitter if, when this storm of history is over, the best epitaph that anyone could write of us was only that: 'The wisest men who had not the gift of foresight'."

You will have lost something if you do not read this book. Something worth while for your well being, for your future, and all our futures. For it has started something of which few can see the end, but which all must deeply ponder, who believes, as I do, in the indomitable Snow man's outlook on the most controversial issue of modern times.—J. LAURENCE PRITCHARD.

SPACEFLIGHT TECHNOLOGY. *Proceedings of the First Commonwealth Spaceflight Symposium. Edited by Kenneth W. Gatland. Academic Press, London*, 1960. 365 *pp. Illustrated.* 75*s.*

This volume includes the major papers presented by Commonwealth contributors at a three day Symposium held in August, 1959 under the aegis of the British Interplanetary Society. The absence of a Space Research programme in any way comparable with those of Russia and the United States has been a source of great regret to a number of individuals and organisations concerned with the advance of British and Commonwealth scientific and technological progress. This Symposium was held to examine the capabilities of the Commonwealth to embark upon original space research of its own in order to maintain its technological, scientific and economic position in the years to come.

The papers published range over a very wide field, but divide naturally into two categories, one concerning the economics of possible research programmes and the scientific and technological potential of the Commonwealth, and the other, actual technological problems such as possible launching vehicle designs, solutions to the problems of manned re-entry from orbit, nuclear propulsion and instrumentation techniques.

Although a high standard is maintained in the majority of the contributions, particularly in the economic surveys, there is a certain lack of reality in some of the vehicle design proposals. This would appear to stem from the inevitable lack of contact of some of the contributors with actual rocket vehicle project work.

Since the Symposium was held, joint Anglo-French proposals have been put forward for a "European Space Club" with participants from most European countries and the Commonwealth. If this project comes to fruition, many of the aims of the Symposium will have been attained, although in a field of co-operation even larger than the organisers and contributors imagined.—H. G. R. ROBINSON.

HEAT TRANSFER. *Alan J. Chapman. Macmillan, New York. 1960. 452 pp. Diagrams. 63s.*

The value of this book comes mainly from the author's thoroughness in explaining the details of this complex subject. The book contains about 380 pages of text covering the three modes of heat transfer at a standard suitable for university work immediately before and after graduation; the remaining 70 pages contain numerous references and examples at the ends of the chapters, and a useful collection of tabulated values of the thermal properties of various materials—a collection unusually comprehensive for this type of book. The author's style of writing is academic and painstaking, in keeping with the general character of the book.

Of the thirteen chapters, three are introductory, the first two being concerned with the basic laws of the subject and the physical quantities of importance in it, while Chapter Six presents the fluid mechanics of boundary layers as a preliminary to the following two chapters on forced convection. Of these two, one contains analytical solutions of the velocity and temperature boundary layers in steady constant-density laminar flat-plate flow, using the Pohlhausen polynomial approximations, together with the solutions for the corresponding turbulent case based on the one-seventh power velocity distribution law and the Prandtl analogy; the other chapter presents a collection of correlations of experimental results to enable problems involving more advanced flows to be solved, in particular constant-density flow in pipes and annular ducts and compressible flow over flat plates and cones. The justification for this arrangement is that such theoretical backing as exists for the "working formulas" given is beyond the scope of the book.

The treatment in the chapters on free convection and on heat transfer in condensation and boiling is similar to that for forced convection, a section on dimensional analysis acting as a link between elementary formal analysis and a collection of working formulae.

The theoretical content of the chapters on these foregoing topics is understandably restricted, and it appears to the reviewer that the author has attempted to make up for this in the chapters on conduction and radiation with the result that they are too full of analytical material, involving considerable repetition and few fresh principles. For example, in Chapter Four on conduction, forty pages are devoted to the analytical treatment of extended surfaces of various shapes, while in Chapter Eleven another considerable slice of the book is spent in obtaining various radiation shape factors.

This constitutes the chief criticism of the book; a less serious one concerns the omission of any reference to several dimensionless quantities of importance, of which at least Stanton number should surely have found a place. Nevertheless it must be reaffirmed that what he does the author does thoroughly, leaving little room for doubt in the reader's mind; there are many students for whom this is the best approach.

Topics covered in the book, but not so far mentioned in this review, are: steady one-dimensional conduction, conduction with two or more independent variables (including transient heat-conduction problems) and problems involving two or three modes of heat transfer (including sections on thermometric errors and simple heat-exchanger analysis).

The production of the book is excellent—but the price is 63s.—S. J. PEERLESS.

LUDWIG PRANDTL. *Gesammelte Abhandlungen zur angewandten Mechanik, Hydro und- Aerodynamik. Compiled by W. Tollmien, H. Schlichting and H. Görtler; edited by W. Riegels. Springer, Berlin* 1961. *In German.* 1620 *pages in three volumes. Illustrated.* DM.273.

Prandtl's treatises (about 130), as compiled by Tollmien, Schlichting and Görtler on behalf of the Max-Planck-Society, more than fulfil the purpose of the publication—to create, in the bibliography of aeronautics, a monument to Prandtl's work. In any of these treatises the mental stature of the author is at once apparent, and this is enhanced by his tireless ingenuity, intuition and breadth of view.

After a Foreword by Professor Betz and Professor von Karman, both of whom had long associations with Prandtl and his work, a concise Introduction by Tollmien, one of Prandtl's many successful scholars, presents Prandtl's activities and achievements so widely known and applied today, particularly in the various fields of aeronautics, in biographical perspective.

The eight-page list of contents, of all three volumes, is repeated in each volume. The first volume also lists, in chronological order, Prandtl's publications over the years from 1900 to 1956. The first paper, on lateral buckling of beams, Prandtl's dissertation for a doctorate at Munich University, discloses already the ingenuity and discipline of the academic mind as outstanding. Further papers in the first volume refer to elasticity, plasticity, rheology, aerofoil and airscrew theories. One paper "Application of Modern Hydrodynamics to Aeronautics" is reproduced in the English translation as published in N.A.C.A. Report 116 (1921).

The second volume contains the papers on boundary layers, drag, turbulence, the generation of vortices and his papers on gas dynamics. Among these classical papers the one "On The Generation of Vortices in Fluids of Small Viscosity" and that "On the Role of Turbulence in Technical Aerodynamics" are presented in the English translations as read before the Royal Aeronautical Society as the Wilbur Wright Memorial Lecture 1927 and the World Engineering Congress at Tokyo in 1929 (Paper No. 904, 1931), respectively.

The third volume of the present work includes the papers dealing with applications to meteorology, experimental techniques in aeronautical research and variae, these last comprising papers relating to vector analysis and problems, some of which are of topical interest, *e.g.* heat transfer in pipes, principles of surfaced tension and aircraft noise. The paper "Hydrodynamic Theory of Bearing Lubrication" (London, 1937) is given in the English translation.

Following lists of Prandtl's publications not included in the present work and of more than 80 dissertations for doctorates supervised by him, the work concludes with biographical data and details of his many awards.—E. S. KRAUSS.

STARTEN UND FLIEGEN. *Editors Otto Fuchs, Wolfgang von Gronau, Eugen Sänger. Deutsche Verlags-Anstalt, Stuttgart,* 1960. *In German.* 385 *pp. Illustrated.* 16.80 D.M.

This is the fifth volume of an annual series which reviews progress for the preceding year in the numerous technologies, processes and applied sciences which are connoted by the term aeronautics (and now, astronautics).

The present volume contains contributions by acknowledged experts on such topics as:—supersonic transports, radar applications, lunar missions, rocket propellants, rockets in meteorology, as well as the perennial aspects of aircraft construction, instrumentation and aerodynamics. As Dr. Benecke states in the introductory chapter the emphasis is on speed and power for propulsion. An interesting but, in this context, anomalous inclusion is a series of descriptions and photographs of renowned sailplanes.

Another chapter which makes interesting reading and, by the present time-scale is almost "historical," gives an account of the first flights with ram-jet engines. The tests were under the supervision of Dr. Eugen Sänger. The primitive but large ram-jet units were pylon-mounted on Dornier 217 aircraft. At the other end of the book's "time scale" is an account by Dr. Geratewohl of the successful launching and recovery of the Rhesus monkeys Able and Baker in a nose cone capsule of a Jupiter rocket. In the realm of space research results and facts soon outpace publications such as this, but Kraft Ehricke anticipates this in his contribution on astronautic targets for 1965-1985.

Those who, by choice, or under duress, regularly read the aeronautical periodicals will not find much new factually in "Starten und Fliegen" but the book adequately fulfils its aim of summarising scattered information and informed opinion into a very readable text easily assimilated by the non-specialist and providing a useful brushing-up exercise for the technical expert. Photographs and printing are of high quality.—F. A. BLAKE.

Additions to the Library

Advances in Cryogenic Engineering. Vol. 6. Edited by K. D. Timmerhaus. Plenum Press, Inc. 1961. 662 pp. Illustrated, $17.50. The Proceedings of the Sixth National Cryogenic Engineering Conference held in August 1960 at Boulder, Colorado. Presents current research in low temperature engineering in such areas as space technology, superconductivity, transfer phenomena, physical equilibria, cryogenic equipment, mechanical properties, and heat transfer and thermometry.

"Aeroplane" Directory of British Aviation, 1961. Temple Press, London. 1961. 547 pp. 35s. Although published "in association with *The Aeroplane and Astronautics*" the publication, thank goodness for nostalgia, retains its "old fashioned" title. One could wish that the Directory appeared at a time when the latest information on the Society's Council is available, but we can no more expect the publishers to delay publication than they can expect the Society to anticipate its elections.

The 1961 Aerospace Year Book. American Aviation Publications, Inc., Washington D.C. 1961. 483 pp. Illustrated. $10. It can be assumed that the transition from *Aircraft Year Book* with the present title in its second year is complete. The pattern remains the same—a review of the year that is past and the present state of the whole of the industry, military aviation, civil aviation and relations with the Government. To anybody concerned with the overall picture of aeronautics and aerospace in the United States it is invaluable.

Agard Manual on Aeroelasticity: Vol. V. Factual Information on Flutter Characteristics. *General Edilor* W. P. Jones. AGARD, Paris, 1961. 73 pp. Diagrams. No price. *To be reviewed jointly with Vol. I.*

AGARDograph 45. Operations from Unprepared and Semi-Prepared Airfields. **AGARDograph 46.** Symposium on Vertical and Short Take-Off and Landing Aircraft. Two parts. AGARD, Paris. 1960. 99, 621 pp. Illustrated. Presented. Two useful and interesting AGARD publications. The first is a comprehensive report in three parts: unprepared landing areas, design criteria for landing gear, classification of aircraft suitable for operating from such areas. The second is the record of a symposium, attended by 268 participants from NATO countries in June 1960. The two parts contain 19 papers subdivided by subject into General Studies and Aerodynamic Aspects, Engine Configurations and Engine Installations, Ground Proximity Effects, Safety and Reliability, Flying Qualities and Vulnerability.

Aircraft Electrical Practice. Lewis F. Wainwright. Odhams, London. 1961. 320 pp. 45s. *To be reviewed.*

Aircraft Instruments. C. A. Williams. Odhams, London. 1961. 240 pp. Illustrated. 35s. *To be reviewed.*

Air Commerce Traffic Pattern (Scheduled Carriers). Fiscal Year 1960 (Revised). U.S. Federal Aviation Agency. U.S.G.P.O., Washington. 40 pp. 3s. 2d. Traffic figures covering every town in the U.S.A. where aircraft ever land ("Large hubs, medium hubs and small hubs").

Airport Terminal Building. U.S. Federal Aviation Agency. U.S.G.P.O., Washington. 86 pp. 5s. A "child's guide" to layout, etc., giving barest requirements. Profusely illustrated.

Algebra: an elementary text-book. G. Chrystal. (Two volumes). Chelsea Publishing Co., New York. 1959. 571, 616 pp. 2.95 dollars each volume. A reprint of two volumes of a classic textbook.

Artificial Earth Satellites. Vols. 3, 4 and 5. *Edited* by L. V. Kurnosova. Plenum Press, New York. 576 pp. Illustrated. $15. Translated from Russian, documenting Soviet achievement in space technology. Contains in all 38 papers by Soviet research workers covering the subject of celestial mechanics, satellite tracking, atmospheric physics, meteorites, instrumentation involved in space satellites and rocket experiments.

Aviation Directory of Asia (including Australia and New Zealand). 1961. R. Vaughan-Fowler (*Editor*). Bombay, Aeronautical Publications of India. 1961. 391 pp. £1. This publication must have a narrow interest in this country, but should be found on the shelves of any library with any aeronautical connections. Conveniently tab-indexed it has sections entitled India, Tourist (including short descriptions of places of interest, agents, hotels), Near and Middle East, Far East, Australia and New Zealand, World Aeronautical Organisations and Who's Who. This is the sixth edition.

The Birth of The Bomb. Ronald W. Clark. Phoenix House, London. 1961. 209 pp. Illustrated. 16s. "The Untold Story of Britain's Part in the Weapon that Changed the World." The material was gathered from interviews with many of the nuclear physicists engaged on the British work on the uranium bomb. It describes the work at Liverpool University in the early months of the war; how Professors Peierls and Frisch discovered in Birmingham in February 1940 that the bomb appeared to be a practicable possibility; how the Maud Committee was set up under Professor (now Sir George) Thomson; the work of the scientists involved; and the effect of the Committee's report on the Americans.

British Miniature Electronic Components and Assemblies and Assemblies Data Annual. 1961-1962. *Edited* by G. W. A. Dummer and J. MacKenzie Robertson. Pergamon, London. 479 pp. Illustrated. 80s. The first of an annual series giving technical data on miniature components (up to approximately 1 in. cube). Contains 18 pages of obvious advertisements and the text appears to be largely photographed from manufacturers' brochures, so that the price seems unnecessarily high.

Cobalt Monograph. *Edited* by Centre d'Information du Cobalt and prepared in collaboration with the staff of Battelle Memorial Institute, Columbus, Ohio, U.S. 1960. 515 pp. Illustrated. B.F. 750. Available from M. Weissenbruch, 49 rue du Poinçon, Brussels. Assembles up-to-date information on the occurrence, mining and extractive metallurgy of cobalt. The available data on the physical, chemical and mechanical properties of the element itself and a study of cobalt alloy systems.

Das Buch der deutschen Fluggeschichte. Peter Supf. Drei Brunnen Verlag, Stuttgart. 1958. 731 pp. Illustrated. (*In German*). DM 39. The second volume (1913-1932) of a comprehensive trilogy, the first of which was reviewed in the May 1957 JOURNAL (p. 364) as "a magnificent book of permanent and authoritative value."

Dynamics of Real Fluids. Second Edition. E. G. Richardson. Edward Arnold, London. 1961. 231 pp. Illustrated. 50s. An enlarged edition of the book first published in 1950. New chapters on hypersonic flow, particulate phenomena and magnetohydro-dynamics. The author's recent experiments on the sounds of impact of a solid on a liquid surface, and on the threshold and initiation of cavitation are described.

Fatigue Testing and Analysis of Results. *Edited* by W. Weibull. Pergamon, Oxford. 1961. 305 pp. 84s. *To be reviewed.*

Freilaufkupplungen: Berechnung und Konstruktion. Karl Stölze and Sigwalt Hart Springer, Berlin. 1961. 169 pp. Illustrated. DM 31.50. *To be reviewed.*

Gas Sampling and Chemical Analysis in Combustion Processes. G. Tiué. Pergamon, Oxford. 1961. 94 pp. Diagrams. 42s. *To be reviewed.*

Magnetic Tape Instrumentation. G. L. Davies. McGraw-Hill, London. 1961. 263 pp. Diagrams. 66s. *To be reviewed.*

La Méchanique du Vol. Performances des Avions et des Engins. L. George and J. F. Vernet. Béranger, Paris. 1960. 465 pp. Diagrams. 98 NF. *To be reviewed.*

Military Handbook of Aircraft Extruded Shapes and Dies. U.S. Department of Defense. U.S.G.P.O., Washington.

Sectional Pagination. £2 14s. 0d. Pages of dimensions, standard sections and their dimensions. Loose leaf.

Modern Flight Dynamics. W. Richard Kolk. Prentice-Hall International, London. 1961. 288 pp. Diagrams. 50s. *To be reviewed.*

My Polar Flights. Umberto Nobile. Frederick Muller London. 1961. 288 pp. Illustrated. 25s. *To be reviewed.*

Non-convertible Coatings. Part I. The Oil and Colour Chemists' Association. Chapman & Hall. 1961. 326 pp. Illustrated. 30s. The first of six parts of a manual on paint technology, written by specialists. It follows the syllabus for the theoretical and practical work of the Non-convertible Coatings Section of the City and Guilds Examination in Paint Technology.

Photoelasticity. Jessop and Harris. Dover Publications, New York. 1960. 184 pp. Illustrated. $2. Another Dover reprint of a classic all will welcome.

Pressure Vessel and Piping Design: Collected Papers, 1927-59. American Society of Mechanical Engineers, New York. 1960. 710 pp. Charts. $10. A collection of papers from various sources under ten headings: openings, bolted-flanged joints, heads, shells, piping, materials and fabrication, thermal stress and fatigue, loads and supports, external pressure, miscellaneous.

Principles of Inertial Navigation. C. J. Savant, R. C. Howard, C. B. Solloway and C. A. Savant. McGraw-Hill, London. 1961. 254 pp. Illustrated. 76s. *To be reviewed.*

Progress in Aeronautical Sciences. Vol. I. *Edited* by A. Ferri, D. Küchemann and L. H. G. Sterne. Pergamon, Oxford. 1961. 280 pp. Diagrams. 80s. *To be reviewed.*

Projective Geometry of *n* dimensions. Otto Schreier and Emanuel Sperner. Chelsea Publishing Co., New York. 1961. 208 pp. $4.95. One of two volumes of the English translation of the well-known German textbook *Einfuehrung in die Analytische Geometrie und Algebra.*

Science in Space. L. V. Berkner and Hugh Odishaw. McGraw-Hill, London. 1961. 457 pp. Illustrated. 54s. 6d. *To be reviewed.*

A Social History of Engineering. W. G. H. Armytage. (*Technology Today and Tomorrow* series). Faber and Faber, London. 1961. 378 pp. Illustrated. 42s. By the Professor of Education, University of Sheffield, tracing the history of the application of human ingenuity to the practical problems of life. From such remarkable technical achievements as the Pyramids, Knossos, and the Roman aqueducts, to the present day.

Sounds of the Twentieth Century. U.S. Federal Aviation Agency. U.S.G.P.O., Washington. 166 pp. 1s. 5d. Apparently written to excuse jet noise, "The Federal Aviation Agency pledges its fullest co-operation in any lawful aircraft noise abatement efforts." Why *lawful*?

Soviet Man in Space. Soviet Booklet No. 76. Soviet Booklets, London. 72 pp. Illustrated. 1s. 6d. A handy little booklet, "for the record." Contains the official announcement of the orbit, Kruschev's talk with Gagarin, a description of the celebrations and other trivia. A report of the flight is reproduced from the Soviet press. The booklet is in no respect technical.

Space Astrophysics. W. Liller. McGraw-Hill, London. 1961. 272 pp. Illustrated. 77s. 6d. Lectures by leading American space astrophysicists and international scientists at the University of Michigan in 1959-60. A detailed description of the first astronomical experiments made from artificial satellites and space probes and some of the related theoretical investigations. In three parts—The Experiments, The Theory, The Instrumentation.

Strictly Birdmanship. Bernard S. Benson. Benson-Lehner Corporation, Santa Monica, California. 1960. 80 pp. Illustrated. $3. While the cartoons of which this book is made up are aimed at the target of Government administration, it can be appreciated by an English readership. The author appears to have combined the techniques of Parkinson (of the Law) and Potter (of the ploys) for the captions to his amusing cartoons. Copies at one guinea may be obtained from Benson-Lehner G.B.) Ltd., West Quay Road, Southampton.

Structure of the Moon's Surface. Gilbert Fielder, Pergamon, Oxford. 1961. 266 pp. Illustrated. 50s. Intended for both the professional scientist and the amateur lunar astronomer, this book is based on observational data which the author has assembled and studied. Part I reviews and summarises important physical problems; relatively new facts or ideas, insufficiently emphasised in the past, are discussed in Part II.

Tables and Nomograms for the Processing of Observations made on Artificial Earth Satellites. I. D. Zhongolovich and V. M. Amelin. Pergamon Press, Oxford. 1961. 190 pp. £5. Translated from the Russian, this gives, as well as the tables and nomograms, a description of their formation and rules for using them. Intended for amateur astronomers as well as specialists.

The Forgotten Ones. The Story of the Ground Crews. Sir Philip Joubert de la Ferté. Hutchinson, London. 1961. 255 pp. Illustrated. 25s. *To be reviewed.*

Theory of Elastic Stability. S. P. Timoshenko and J. M. Gere. Second Edition. McGraw-Hill, London. 1961. 540 pp. Diagrams. £5 16s. 6d. A second edition of the 1936 classic, thoroughly revised, with new material on the elastic buckling of bars under the action of non-conservative forces, periodically varying forces and impact, on the inelastic buckling of bars, on torsional buckling, on the lateral buckling of beams, and on the buckling of rings, curved bars and arches. In the chapter on the buckling of plates, tables for calculating critical stresses are added and new material on the buckling of shells includes a discussion of post-buckling behaviour of compressed cylindrical shells.

The Theory of Subsonic Plane Flow. L. C. Woods. Cambridge University Press, London. 1961. 594 pp. Diagrams. 60s. *To be reviewed.*

War Planes of the Second World War: FIGHTERS. Vols. II and III. William Green. Macdonald, London. 1961. 192, 181 pp. Illustrated. 9s. 6d. each volume. The next two volumes in the alphabetical series, of which the first was reviewed briefly in the December 1960 JOURNAL (p. 779). Details of all aircraft, both operational and experimental prototypes, of all combatant countries. Each aircraft is illustrated with photographs, many previously unpublished, and a three-view line drawing. These volumes cover the fighters of Great Britain and Italy (Vol. II) and of Japan, the Netherlands, Poland, Rumania and the Soviet Union (Vol. III). Vol. IV will deal with the U.S. and Yugoslav fighters.

World Survey of Civil Aviation: Africa. U.S. Department of Commerce. U.S. Department of Commerce, Washington. 57 pp. 2s. 3d. Second in a series of foreign market surveys of civil aircraft and aeronautical products.

S.A.E. PREPRINTS

S.A.E. National Aeronautical Meeting 1961

335A Selection of freight consolidation systems for air transport. W. H. Obrecht and N. B. Helmes.

335B Unitization—a stimulus to air freight. E. W. Fuller.

335C Air cargo is here to stay, if . . . . . C. Froesch.

335D Air cargo development—what sets the course? E. Johnson.

336A The production man's role in product reliability. H. P. Kean.

336B What do you really pay for reliability? L. M. Steward.

336C Time and failure reporting. C. W. Russell.

337A Lift—thrust turbofan engines for VTOL and STOL aircraft. P. H. J. Young.

337B New types and applications of turbine engines for short and vertical take-off. J. M. Stephenson.

337C Evaluation of Army's VTOL test beds. J. Beebe.

337D Factors involved in selection of VTOL transport configuration. R. E. Kuhn and M. O. McKinney.

338A Advantages of a medium thrust nuclear-electric rocket. R. W. Hallet and S. Gronich.

338B Minimum-volume gas-cooled nuclear heat exchangers. C. D. Fulton and W. B. Thomson.

338C Nuclear engine operating considerations. G. W. Newton.

338D Nuclear ramjet control system design, performance, environmental requirements. M. M. Weintraub.

339A Transient effects of nuclear radiation on electronic equipment. J. W. Clark and T. D. Hanscome.

339B Radiation effects on materials and equipment. M. J. Oestmann and J. F. Kircher.

339C Determination of the effects of satellite environment on the thermal radiation characteristics of surfaces. R. E. Gaumer.

340A High energy forming new manufacturing techniques. J. P. Orr.

340B Shearforming 7075 aluminum. C. E. Howle and F. Jacobs.

340C Distortion control during heat treatment of aircraft and missile components. A. L. Kitchin and H. Mansfield.

340E Welding and brazing of refractory metals. G. M. Slaughter.

340F The fabrication of high thrust lightweight jet engines. S. Weiss and D. E. Hacker.

340G Brazing of sandwich structures of columbium alloys. M. M. Schwartz.

340H Applications of the plasma arc in fabrication. R. L. O'Brien.

340J Hot machining of high temperature alloys can increase production. J. L. Wennberg *et al.*

340K Small hole gun drilling of superalloys. D. A. Stewart.

340L Distortion and residual surface stress in grinding and milling of high strength steels. L. J. Nowikowski *et al.*

341A The commercial supersonic transport—some operational considerations. J. G. Borger *et al.*

341B The supersonic transport: pilot views on operational goals, handling characteristics, and related subjects, W. W. Moss *et al.*

341C Passenger density and accommodations as factors in supersonic transport design. P. Shipps and J. Frick.

341D Considerations in selection of wing and fuselage sheet materials for trisonic transports. W. F. Brown *et al.*

341E A consideration of powerplants for supersonic transport aircraft. W. H. Sens and T. G. Slaiby.

341F The supersonic transport—required characteristics of configurations. M. R. Nichols.

342A Productioneering in the aerospace age planning—the fundamental technique. T. Hechler.

342B Industrial engineering before the act. J. F. Ringo.

342C The Martin Company's project management method. K. P. Bowen.

342D The implications of producing aerospace weapons at planned low rates. L. R. Koepnick.

342E Meeting productioneering challenge. P. T. Smith.

343A A method for critiquing designs and predicting reliability in advance of hardware availability. R. Bussiere.

343B Reliable spacecraft designs. I. Doshay.

343C Categorization of human errors in rocket engine testing. L. B. Blank and G. S. Miller.

343D Introduction to the theory of reliability. R. P. Haviland.

344A Contributions of Dyna-Soar to space flight technology. Y. A. Yoler.

344B Thermal environment of interplanetary space. J. C. Ballinger *et al.*

344C An inflatable balloon-type deceleration and stabilization system for recovery of space vehicles. F. R. Nebiker.

344D Maintenance, repair and assembly in space by remote means. J. W. Clark.

345A Turbine powered transport aircraft in the U.S.S.R. D. J. Ritchie.

345C Trans-Canada's experience with the Rolls-Royce "Conway" turbine engine. J. T. Dyment and J. J. Eden

345D Axial flow compressor noise studies. J. M. Tyler and T. G. Sofrin.

346B Integrated low thrust solar propulsion-power generation system for communication satellites. B. T. Macauley.

346C Application of electrical thrust devices to propulsion and attitude control of space vehicles. C. J. McDole.

346D Experimental studies of a pulsed plasma pinch space engine. C. C. Cavalconte *et al.*

347A Marine and industrial uses of the Proteus and Olympus engines. B. H. Slatter.

347B Industrial power requirements and the aircraft gas turbine engine. W. J. Closs.

347C One pound/horsepower—new weight standard for ground power. K. A. Austin.

348A Piloting techniques—the changing scene and its associated problems. P. W. Howson.

348B Autoflare landing system for jet transports. R. K. Smyth and E. W. Velander.

348C Integration of gust alleviators in flight control systems. G. M. Andrew and F. H. Gardner.

348D A pilot's view of certification testing and development of operational procedures for jet transports. W. M. Magruder.

349A Significant environmental differences between powerplants for aerospace and underwater missiles. J. F. Brady.

349C A chemically fueled propulsion system for deep submergence. H. L. Howell.

350A Turboelectric power generation for space vehicles. Daniel P. Ross and J. Edward Taylor.

350B Design considerations and development of solar space power test facility. D. C. Miley.

350C Solar thermionic space power systems. R. E. Henderson and D. L. Dresser.

350D The cryhocycle: a new concept in a room-temperature integrated thermal control and power-generation system. John R. May and David H. Silvern.

351A All mechanical servo actuating systems and their relation to the advanced vehicle. D. Grudin and J. L. Hall.

351B A temperature-response diagram. A. S. Lermer.

351C New techniques in automatic flight control system design. E. Hartog and H. Moreines.

352A Acceleration (g) and visual performance. William J. White.

352B Andrometry: a practical application of co-ordinate anthropometry in weapon system design. John. W. Chaffee.

352C Selected methods for atmosphere control in manned space flights. M. G. Del Duca, A. D. Babinsky and F. D. Miraldi.

352D Nuclear submarine habitability. Eugene A. Ramskill.

353A Sonic proof testing B-58 weapons systems. J. R. Ballentine.

353B A system for estimating cumulative fatigue damage by using the miner rule corrected for residual stress. C. R. Smith.

353C Harmonic analysis of bending moments on turbine blades due to irregular temperature distribution at turbine inlet. R. D. Stottle.

354A Thermal radiation as a high temperature energy transport mechanism within solids. H. P. Kirchner and F. A. Vassallo.

354B Dimensional stability together with ablation. Franklin A. Vassallo.

354C Ceramic heat shields for glide reentry vehicles. R. M. Davis.

354D Some stress rupture properties of columbium, molybdenum, tantalum, and tungsten metals and alloys between 2400-5000 F. Al Donlevy and Jack K. Y. Hum.

355A Impact on logistics of hydrofoil amphibians. L. S. Votre and F. Stora.

355B Structural design for safety in high speed hydrofoil ships. Richard G. Merritt.

355C Characteristics of the U.S. Maritime Administration hydrofoil test vehicle. Glen. J. Wennagel.

356A Jet lift VTO—the Short SC.1. H. G. Conway.

356B Jet fuel anti-icing additives—a new concept in safety of flight. W. C. French and E. A. Malick.

Reports

AERODYNAMICS

BOUNDARY LAYER *see also* REFERENCE LITERATURE

*An approximate method for calculating the laminar boundary layer on an infinite swept wing with arbitrary velocity and suction distribution. A. W. Lindfield and H. G. Pinsent. C.P.*516. 1960.—(1.1.1.1×1.1.5.1.)

Laminar boundary layer with injection through a permeable wall. T. N. Stevenson. C.o.A. Report 145. *January* 1961. The steady incompressible laminar boundary layer equations for a perfect gas with arbitrary distributions of wall temperature, main stream velocity and normal velocity at the wall are solved approximately. Equations for the skin friction and the rate of heat transfer are obtained. To assess the accuracy of these equations, solutions are compared with exact solutions for wedge type flow with a wall temperature distribution such that the difference between the wall and the steam temperatures is proportional to a power of the distance from the leading edge. Prandtl number of 0·7 is used. A solution for the skin friction with constant normal velocity at the wall and constant main stream velocity is given.—(1.1.1.1×1.1.1.4×1.9.1).

The growth of compressible turbulent boundary layers on isothermal and adiabatic walls. D. A. Spence. R. & M. 3191. 1961.—(1.1.2.4).

Extension of boundary-layer-separation criteria to a Mach number of 6·5 by utilizing flat plates with forward-facing steps. J. R. Sterrett and J. C. Emery. N.A.S.A. T.N. D-618. Dec. 1960.
The pressure rise at separation, the laminar plateau pressure, and the turbulent peak pressure were determined. The effect of Reynolds number, for the lower Mach number range, and of step height on peak pressure for turbulent boundary layers on plates with forward-facing steps was investigated.—(1.1.4.4).

Effects of cone angle, Mach number, and nose blunting on transition at supersonic speeds. K. R. Czarnecki and M. W. Jackson. N.A.S.A. T.N. D-634. Jan. 1961.
Transition characteristics were determined for smooth, blunt-nosed cones varying from 27° to 60° in included angle. Tests were conducted for Mach numbers from 1·61 to 2·20 and Reynolds numbers per ft. from $1{\cdot}5\times10^6$ to $8{\cdot}0\times10^6$.—(1.1.2.4).

COMPRESSIBLE FLOW *see also* POWER PLANTS
THERMODYNAMICS

Comparison of theoretical and measured surface pressures at $M=1{\cdot}2$ on three bodies having different waistings. W. R. Buckingham. C.P. 520. 1960.
Surface pressures were calculated at $M=1{\cdot}2$ and zero incidence for three bodies, the first with a nose followed by a cylindrical section of constant radius, the second having a waist of circular cross-section and the third a waist of elliptical cross-section with constant depth. These results were compared with the surface pressures measured in the 8 ft. by 6 ft. transonic tunnel at $Re\simeq4\times10^6$ based on body length.—(1.2.2.1).

The characteristics of a two-dimensional supersonic sail. E. A. Boyd. C.o.A. Report 143. *December* 1960.
The two-dimensional supersonic sail is analysed using Busemann's second-order theory. Aerodynamic characteristics are calculated for sails.—(1.2.3.1).

Base-pressure measurements with wire-supported models at supersonic speeds. J. D. Gray. A.E.D.C.-T.N.-61-23. Mar. 1961.
Base pressure measurements were made with an ogive cylinder and a blunt, boat-tailed cone at $M_\infty=4$ to appraise the effects of small wire supports. Measurements with a much larger blunted cone were made at $M_\infty=3{\cdot}5$ and 5. The tests covered a Reynolds number range from about $0{\cdot}06$ to $0{\cdot}48\times10^6$ per in.—(1.2.3×1.12.1.3).

CONTROLS *see* AERODYNAMICS—STABILITY AND CONTROL

FLUIDS DYNAMICS *see also* LOADS
SCIENCE—GENERAL

Some thoughts on the effects of aircraft motion and eddy convection on the noise from air jets. J. E. Ff. Williams. U.S.A.A. Report 155. *September* 1960.
The effect of eddy convection on the noise output of turbulent jets is considered and a new Mach number dependence obtained. The theory of convected source regions is extended for noise from aircraft in flight. The overall convection velocity is estimated from a comparison of flight and static engine tests.—(1.4×5.6×27×32.2.3).

INTERNAL FLOW *see also* POWER PLANTS

The effect of bend outlet conditions on the pressure losses in bent circular pipes. M. E. Martin and E. C. Deverson. C.P. 505. 1960.
A bend radius may be determined for a given pipe diameter such that certain secondary flow conditions are attained at the outlet of a bend of given deflection. The build-up of pressure losses in the bend itself and in the transition region downstream from the bend was investigated for three values of the bend deflection. Similar calculations were made for flow in a helical pipe at the same Reynolds number. The effect of varying the downstream transition length was considered.—(1.5.1.2).

Comparative performance of two aerofoil cascades at high speed. W. Howard and A. P. Cox. A.R.L. Note M.E. 242. *Aug.* 1960.—(1.5.4).

LOADS

Experimental determination of the pressure distribution on a rectangular wing oscillating in the first bending mode for Mach numbers from 0·24 *to* 1·30. *H. C. Lessing* et al. *N.A.S.A. T.N. D-*344. *Dec.* 1960.
The wing was of aspect ratio 3 with 5%-thick bi-convex aerofoil sections. Data were obtained at 0° and 5° angle of attack $0{\cdot}24\leq M\leq1{\cdot}30$. The data are compared with oscillatory pressure distributions computed by the most complete linearised theories available.—(1.6.3×2×33.1.1).

The aerodynamic forces of an oscillating aerofoil in two-dimensional potential flow at speeds slightly below the speed of sound. A. I. van de Vooren and J. Boersma. N.L.L.-T.N. W. 10. *March* 1960.—(1.6.3×2×1.4.1).

STABILITY AND CONTROL *see also* MISSILES

The theoretical evaluation of the downwash behind jet-flapped wings. A. J. Ross. R. & M. 3119. 1961.
The downwash behind jet-flapped wings of infinite and finite span is evaluated. Charts are given for the functions required in calculating the downwash for four specific values of jet momentum coefficient. Results were obtained for the infinite wing and for a wing of aspect ratio 6·0, for various tailplane positions, and varying wing incidence, jet momentum coefficient. Comparison is made with American experimental results for a wing of aspect ratio 8·4.—(1.8.2.1×1.3.4×1.10.1.2).

A study of longitudinal control problems at low and negative damping and stability with emphasis on effects of motion cues. M. Sadoff et al. *N.A.S.A. T.N. D-*348. *January* 1961.
Several types of simulators, including the Johnsville centrifuge, were investigated and also in flight to assess the effects of incomplete or spurious motion cues on pilot opinion and task performance over a range of longitudinal short-period dynamics. Most tests were conducted with a conventional centre stick; but evaluation in the centrifuge of a pencil-type side-arm controller was made.—(1.8.2.1×5).

*A three-axis fixed-simulator investigation of the effects on control precision of various ways of utilizing rate signals. J. W. McKee. N.A.S.A. T.N. D.-*525. *January* 1961.
The control of a vehicle with no inherent stability or damping was studied using a side-arm controller providing proportional acceleration control. Vehicle rate signals provided control feedback or system damping and were used in the instrument display either separate from or summed with displacement signals.—(1.8.0.1×4.2.3×18).

THERMO-AERODYNAMICS *see also* BOUNDARY LAYER
STRUCTURES—THEORY AND ANALYSIS
THERMODYNAMICS

*An analysis of exact and approximate equations for the temperature distribution in an insulated thick skin subjected to aerodynamic heating. R. S. Harris and J. R. Davidson. N.A.S.A. T.N. D-*519. *Jan.* 1961.—(1.9.1×33.2.4.5.9).

WINGS AND AEROFOILS *see* STABILITY AND CONTROL

TESTING AND INSTRUMENTS *see* COMPRESSIBLE FLOW

AEROELASTICITY

See AERODYNAMICS—LOADS
STRUCTURES —LOADS
THEORY AND ANALYSIS

AIRCRAFT

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DESIGN AND CONSTRUCTION

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FATIGUE
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METEOROLOGY

EXTRA-TERRESTRIAL TECHNOLOGY

See MATHEMATICS
STRUCTURES—LOADS
—THEORY AND ANALYSIS
THERMODYNAMICS

On phenomena observed at the instant of impact of the second Soviet cosmic rocket on the moon. O. B. Dluzhnevskaya. R.A.E. Lib. Trans. 938. *Feb.* 1961.
The Astronomical Council of the U.S.S.R. Academy of Sciences has received various accounts of phenomena observed by a number of people when the Lunik hit the surface of the moon. All observations are analysed and summarised in a table. The positions of the observed phenonema are indicated on the map of the moon.—(8.2).

The attainability of heavenly bodies. W. Hohmann. N.A.S.A. T.T. F-44. Nov. 1960.
This work (originally published in 1925) contributes to recognition of the feasibility of space travel. Treated are problems associated with leaving the earth, return to earth, free-space flight, circum-navigation of celestial objects, and landing on other celestial objects.—(8.2×26×27×25.1).

The autoionization effect and its influence on the intensity of certain star spectra lines. A. A. Nikitin. N.A.S.A. T.T. F-56. Dec. 1960.—(8.1×32.2.5).

Theoretical investigations of the ablation of a glass-type heat protection shield of varied material properties at the stagnation point of a re-entering I.R.B.M. E. W. Adams. N.A.S.A. T.N. D-564. January 1961.
The melting-type heat protection at the stagnation point of a re-entering I.R.B.M. is treated by employing homogeneous, opaque, and non-decomposing glass shields which do not exceed a temperature of 460°K at their thermally insulated inner edges. Some effects due to variations of the glass properties are described.—(8.2×21.4).

AVIATION MEDICINE

Physiological effects of acceleration observed during a centrifuge study of pilot performance. H. A. Smedal et al. *N.A.S.A. T.N. D-345. December* 1960.
An investigation in an attempt to establish meaningful human tolerance to acceleration boundaries typical of those which might be encountered by a forward facing pilot flying an atmosphere entry vehicle. The Johnsville Centrifuge was used as a flight simulator and operated as a closed loop system, with a representative control problem. Physiological effects on the circulatory, respiratory, and visual systems are discussed.—(9).

A flight evaluation of an airborne physiological instrumentation system, including preliminary results under conditions of varying accelerations. H. A. Smedal et al. *N.A.S.A. T.N. D-351. December* 1960.
An instrumentation system has been designed at the Ames Research Center to measure the pilot's electrocardiogram, pulse rate, respiration rate, and blood pressure during control studies in flight and in motion simulators. Preliminary observations were made on the effect of subgravity conditions on pulse rate and blood pressure.—(9).

Proceedings of Conference on Radiation Problems in Manned Space Flight. 21st June 1960. *Washington, D.C. G. J. Jacobs (Editor). N.A.S.A. T.N. D-588. December* 1960.
Four problem areas were discussed: (1) the present status of physical measurements of radiation in space, (2) their interpretation in terms of biological effectiveness, (3) further studies needed to define the radiation problems in manned space flight, and (4) how best these studies may be accomplished.—(9×32.2.5).

ELECTRONICS

Statistical design of control systems containing digital devices. Y. Ishii. Aero. Res. Inst., Tokyo, Report 360. *December* 1960.—(11×23.3).

FUELS AND LUBRICANTS

See also SCIENCE—GENERAL
THERMODYNAMICS

Lubrication of two cylindrical surfaces, considering cavitation. L. Floberg. Inst. Machine Elements, Chalmers Univ. Report 14. 1961.—(14.2).

Attitude-eccentricity curves and stability conditions of the infinite journal bearing. L. Floberg. Inst. Machine Elements. Chalmers Univ. Report 15. 1961.—(14.2×23.1).

Experimental investigation of cavitation regions in journal bearings. L. Floberg. Inst. Machine Elements. Chalmers Univ. Report 16. 1961.—(14.2×23.1).

HYDRODYNAMICS

See also STRUCTURES—LOADS
THEORY AND ANALYSIS
THERMODYNAMICS

An experimental determination of the dynamic response of a long hydraulic line. J. D. Regetz. N.A.S.A. T.N. D-576. Dec. 1960.
Data are presented in the form of hydraulic impedance amplitude and phase angle and are compared with curves calculated from theoretical relations derived from basic fluid-flow theory.—(17.1).

INSTRUMENTS AND EQUIPMENT

See AERODYNAMICS—STABILITY AND CONTROL
METEOROLOGY

MATERIALS

See also EXTRA-TERRESTRIAL TECHNOLOGY
FATIGUE
STRUCTURES—THEORY AND ANALYSIS
THERMODYNAMICS

Vibrations in space lattices. M. Born and Th. V. Kármán. R.A.E. Lib. Trans. 930. *January* 1961.
Residual ray frequencies for rock-salt, sylvine and fluorite are calculated. The specific heats of rock-salt and sylvine are calculated and compared to the measured, and other calculated values.—(21.3).

MATHEMATICS

See also STRUCTURES—LOADS
THEORY AND ANALYSIS
TESTING

A method of estimating residuals in orbital theory. M. Lecar. N.A.S.A. T.N. D-493. January 1961.—(22.3×8.2).

Characteristic orbital variables and their time rates in unperturbed elliptic orbits H. G. L. Krause. N.A.S.A. T.N. D-558. December 1960.—(22.3×8.2).

Gyroscopic motion of an unsymmetrical satellite under no external forces. M. E. Kubler, N.A.S.A. T.N. D-596. Dec. 1960.
The results are given of an investigation on the transition from spin about the axis of minimum moment of inertia to spin about the axis of maximum moment of inertia by dissipation of internal mechanical energy.—(22.3×8.2).

MECHANICAL ENGINEERING

See ELECTRONICS
FUELS AND LUBRICANTS

METEOROLOGY

See also SCIENCE—GENERAL

Variations in the density of the upper atmosphere from data on the change of periods of revolution of artificial earth satellites. G. A. Kolegov. R.A.E. Lib. Trans. 934. *Feb.* 1961.—(24).

Interlevel and intralevel correlations of wind components for six geographical locations. W. W. Vaughan. N.A.S.A. T.N. D-561. December 1960.
Tables are provided containing the arithmetic means, standard deviations, and coefficients of correlation for the zonal (East-West) and meridional (North-South) components of the wind at various altitude levels for several geographical locations. The coefficients of correlation were determined (1) between the two wind components at each altitude level (intralevel) and (2) between the same wind component at different levels (interlevel) by one kilometre intervals from the surface to 30 kms. These data provide a statistical description of the vertical wind structure for missile design and performance studies.—(24).

Investigation of low level turbulence encountered by a Sabre Mk. V aircraft over Eastern Canada. D. M. McGregor. N.R.C. Report LR-298. January 1961.—(24 × 5).

Beschreibung der Höhen-und Klimaprüfanlagen. G. Dettmann. D.F.L. Bericht 134. 1960. (*In German*).—(24 × 18).

MISSILES

See also EXTRA-TERRESTRIAL TECHNOLOGY

Aerodynamic characteristics of a model of an inflatable-sphere launching vehicle under simulated conditions of Mach number and altitude. R. B. Robinson and O. A. Morris. N.A.S.A. T.N. D-640. December 1960.
Tests were conducted at low pressures for several model configurations through an angle-of-attack range from −6° to 18° at Mach numbers of 1·89 and 1·98.—(25.2 × 1.8.2.2).

POWER PLANTS

See also AERODYNAMICS—FLUID DYNAMICS
EXTRA-TERRESTRIAL TECHNOLOGY
SCIENCE—GENERAL
STRUCTURES—THEORY AND ANALYSIS
THERMODYNAMICS

Base pressure at supersonic speeds in the presence of a supersonic jet. A. H. Craven et al. *CoA Report* 144. *December* 1960.
The effects on base pressure of jet Mach number, free stream Reynolds number and jet to base diameter ratio have been investigated experimentally.—(27.1.1 × 1.2.3).

Effect of nozzle convergence length on performance of a heptane-oxygen combustor. M. C. Burrows. N.A.S.A. T.N. D-579. December 1960.
Characteristic velocity was evaluated for a nominal 200 lb. thrust combustor with a chamber diameter of 2 in., chamber lengths from 2 to 16 in., and nozzle convergence lengths of 0·25, 3·0 and 6·0 in. A contraction ratio of 6·4 and a single propellant-flow condition were used. Two injectors with widely different characteristics were used to produce a heptane-spray gaseous-oxygen atmosphere.—(27.3 × 1.5.1).

A proposed aircraft lift/thrust power plant arrangement. R. A. Tyler. N.R.C. Report L.R. 293. *Dec.* 1960.—(27.1.3.1 × 3.12).

REFERENCE LITERATURE

Bibliographie der Veröffentlichungen 1907-1959. *Max-Planck-Inst. Mitt.* 25. 1960. (*In German*).—(30.1 × 1).

FATIGUE

See also STRUCTURES—THEORY AND ANALYSIS
THERMODYNAMICS

The effect of the ground to air to ground cycle on the life of transport aircraft wings which are subject to gust loads. E. Gassner and K. F. Horstmann. R.A.E. Lib. Trans. 933. *Feb.* 1961.
The lives of transport aircraft wings are, to a large extent, limited by gust loads and the so-called ground to air cycle.—(31.2.4.2 × 4.2.2.5 × 21.2.2 × 31.2.2.3.2.3).

SCIENCE—GENERAL

See also AERODYNAMICS—FLUID DYNAMICS
EXTRA-TERRESTRIAL TECHNOLOGY
AVIATION MEDICINE

Theoretical treatment of phenomena in rarefied gases. B. Baule. R.A.E. Lib. Trans. 932. *February* 1961.
The temperature discontinuity, slip, molecular thermal conductivity and internal friction for rarefied gases moving between two plates are considered. Calculations are made for hydrogen, oxygen and carbon dioxide. The results are compared with experimental results and those of earlier workers.—(32.2 × 34.4).

International Geophysical Year information. Bulletin No. 7. *N.A.S.A. T.T. F-50. November* 1960.
Included are papers on the dependence of the frequency of appearance of noctilucent clouds upon the date and the geographical latitude; control of permanency of airglow transparency; movements of winds in the F2 layer, which were made by the phase method; and on foreign methods of observations made with rockets and artificial earth satellites.—(32.2 × 24).

Concerning a method for the measurement of very high temperatures in nearly transparent arc columns. R. W. Larenz. N.A.S.A. T.T. F-54. December 1960.
A method of measuring the temperature distribution across an arc column using a spectrograph. An equation is developed for the determination of the electronic temperature that corresponds to the point of maximum spectral line intensity across an arc column. A graphical solution relates various parameters such as statistical weights, excitation potential, pressure, etc., to spectral line intensity and temperature.—(32.2.5 × 27.7).

Revaluation of ionospheric electron densities and collision frequencies derived from rocket measurements of refractive index and attenuation. J. A. Kane. N.A.S.A. T.N. D-503. Nov. 1960.
Measurements of the refractive index and attenuation coefficient for a 7·75 Mc radio wave were made from rockets passing through the D-region of the ionosphere. The "effective" electron collision frequencies and electron densities were derived from these measurements by use of the Appleton-Hartree formula; these results were published.—(32.2.5).

Experiments with plasmas produced by potassium-seeded cyanogen oxygen flames for study of radio transmission at simulated re-entry vehicle plasma conditions. P. W. Huber and P. B. Gooderum. N.A.S.A. T.N. D-627. January 1961.
Appendix A: Preliminary attenuation measurements of 219·5 mc. propagation through the plasma. Theo. E. Sims and Duncan E. McIver, Jr. Appendix B: Diagnostic and Transmission studies of the plasma using microwave techniques. Joseph Burlock and William L. Grantham.
Experiments using this method of plasma production are described, and the ability to simulate plasma conditions on re-entering hypersonic vehicles is indicated. Radio-signal-loss data are presented.—(32.2 × 1.4.4).

Contribution a la chimie des solutions aqueuses de titane tétravalent. C. J. Garrigues. Pubs. Sc. et Tech. N.T. 93. 1960 (*In French.*)—(32.1).

STRUCTURES

LOADS *see also* AERODYNAMICS—LOADS
STRUCTURES—THEORY AND ANALYSIS

A two-sided evaluation of critical forces. I. A. Kamyshko. R.A.E. Lib. Trans. 925. *Dec.* 1960.
Starting from the fact that the Rayleigh-Ritz and Galerkin methods of estimating the critical end load of a strut overestimate the load, and that Dunkerley's method leads to an under-estimate, it is shown by Green's function that similar over-estimates and under-estimates can be obtained for the critical (or natural) frequencies of laterally vibrating beams.—(33.1.2 × 33.2.4.1.1).

Analytical study of soft landings on gas-filled bags. J. B. Esgar and W. C. Morgan. N.A.S.A. T.R. R-75. 1960.
An analytical procedure was developed that is valid for bags of various arbitrary shapes and is applicable to planetary or lunar landings for sinking speeds that are small compared to the sonic velocity of the gas within the bag. For landing on the earth at speeds consistent with normal parachute descent, the relative merits of four bag shapes were evaluated with and without gas bleed from the bags. Deceleration and onset rates acceptable for well-supported humans seem feasible.—(33.1.2).

Use of subsonic kernel function in an influence-coefficient method of aeroelastic analysis and some comparisons with experiment. J. L. Sewall et al. *N.A.S.A. T.N. D-515. Oct.* 1960.
This method of analysis is developed for calculating the response of a flexible wing to a sinusoidal force in an air stream and for treating such aeroelastic instabilities as flutter and divergence. Aerodynamic influence coefficients are derived by the kernel-function procedure and application is made to a uniform cantilever wing-tip tank configuration for which responses to a sinusoidal force and flutter speeds were measured over a range of subsonic Mach numbers.—(33.1.2 × 33.2.3.1.10 × 2).

The in-plane vibrations of a flat spinning disk. J. G. Simmonds. N.A.S.A. T.N. D-521. Oct. 1960.
The static and vibrational in-plane deformations of a thin, flat, elastic, homogeneous disc rotating at a constant speed is analysed. A disc attached to a rigid central hub of finite diameter and a freely spinning disc are considered.—(33.1.2 × 33.2.4.10.7).

Experimental investigation of the natural frequencies of liquids in toroidal tanks. J. L. McCarty et al. *N.A.S.A. T.N. D-531. Oct.* 1960.
Several toroidal tank configurations applicable to missile and space-vehicle liquid storage systems were oscillated to study the natural frequencies of the anti-symmetric modes of contained liquids over a range of liquid depths and tank sizes. Natural frequencies were obtained for tank oscillations parallel to the free surface for both horizontal and vertical tank orientations. —(33.1.2×33.2.4.11.10).

Applications of a general finite-difference method for calculating bending deformations of solid plates. W. C. Walton. N.A.S.A. T.N. D-536. November 1960.
The results are given of some applications of a finite-difference technique for calculating small static or simple harmonic flexures of plates and beams. The applications consisted of calculations of the natural modes and frequencies of several uniform-thickness cantilever plates and of the uniform free-free beam. An appendix gives computing procedures which facilitate application of the technique in conjunction with high-speed computing equipment.—(33.1.2×33.2.4.1.10×22.2).

A study of the feasibility of inflatable reentry gliders. W. B. Olstad. N.A.S.A. T.N. D-538. Oct. 1960.
The results indicate that such vehicles appear to be feasible and could be constructed with present technology. The study configuration had a wing loading of 1·5 lb./ft.² and could operate within an angle of attack range from 11° to 66° and at initial entry angles from 0° to −2·5° for a maximum leading-edge temperature of 1300°F.—(33.1×8.2).

Theory of the fluid oscillations in a circular cylindrical ring tank partially filled with lqiuid. H. F. Bauer. N.A.S.A. T.N. D-557. December 1960.
The response of a propellant to sinusoidal forced motions, as translational, rotational, and bending oscillations of the tank walls, is treated for a circular cylindrical ring tank. The liquid in the tanks was considered to be incompressible and non-viscous. Numerical results are given for surface displacement, fluid force, and moment.—(33.1.2×33.2.4.3×17.1).

Landing characteristics of a reentry capsule with a torus-shaped air bag for load alleviation. J. R. McGehee and M. E. Hathaway. N.A.S.A. T.N. D-628. November 1960.
Landing tests were made of a 1/6-scale dynamic-model configuration to determine accelerations and motions for nominal flight paths 60° and 90° (vertical), contact attitudes from −25° to 30°, and a vertical velocity of 12·25 ft./sec. at contact.—(33.1×8.2).

An analysis of the flapwise bending frequencies and mode shapes of rotor blades having two flapping hinges to reduce vibration levels. G. W. Brooks and H. W. Leonard. N.A.S.A. T.N. D-633. December 1960.
The equations of motion are derived for a blade of variable mass and stiffness distribution. Solutions are presented for a typical blade of constant cross section having a wide range of hinge locations.—(33.1.2×4.4).

An experimental investigation of the influence of the wake on the torsional oscillations of airscrew blades at low mean incidences. A. G. Shutler. A.A.S.U. Report 152. *Dec.* 1960.
A test rig designed to study "Wake Effect" on the torsional oscillations of airscrew blades at low mean incidences is described; the results obtained are given and compared with the theoretical predictions of Jones and Loewy.—(33.1.2×4.4).

THEORY AND ANALYSIS *see also* THERMO-AERODYNAMICS
STRUCTURES—LOADS
WEIGHT ANALYSIS AND CONTROL

Automatic control of laboratory representation of kinetic heating. J. Taylor. C.P. 532. 1961.
The purpose of the control system is to heat an aircraft structure by electrical power in the laboratory in a manner representative of the heating it receives in flight from its motion through the air.—(33.2.4.09×1.9.1).

Linear buckling of an axially reinforced pressurised cylinder. D. S. Houghton and D. J. Johns. C.o.A. Note 110. *Oct.* 1960.
An analysis is presented using small deflection theory for the buckling of a pressurised, axially reinforced cylinder, which is subject to axial compression. Various approximations to the analysis are discussed and some results are presented which show the effects of internal pressure and various structural parameters on both buckling and overall buckling.—(33.2.4.3.1).

An analysis of an unstiffened cylindrical shell subjected to internal pressure and axial loading. D. S. Houghton and D. J. Johns. C.o.A. Note 114. *March* 1961.
Equations are obtained for the deflections and stresses in long thin unreinforced cylinders, subjected to an axial load. Results show the variation of the structural weight parameter with the structural axial loading index for pressurised and unpressurised shells. An allowance is made for the effects of shell initial eccentricities on the buckling stress coefficient K in accordance with R.Ae.S. data sheet 04.01.01—(33.2.4.3.1×33.2.4.3.7).

The effect of various parameters on wing-torsion aileron-rotation flutter. A. D. N. Smith. R. & M. 3168. 1960.
The effect of certain parameters on binary wing-torsion aileron-rotation are considered in a simplified analysis. These parameters are aileron circuit stiffness, aileron mass-balance, altitude and structural damping.—(33.2.3.1.5×2)

The hydro-elastic stability of hydrofoil struts. D. V. Hilborne. R. & M. 3172. 1960.
Hydrofoil struts are liable to failure through divergence or flutter. The theory developed to describe the aeroelastic stability of aircraft wings is applied to provide predictions of the speeds of onset of the two kinds of instability; a simplified analysis of how the divergence speed depends on strut length and rake is included. Results of experiments on the variation of divergence speed with strut length and flutter speed with rake are given.—(33.2.4.2.5×33.2.4.2.10×17.2).

Blade vibratory stresses in a multi-stage axial-flow compressor. D. A. Kilpatrick et al. *R. & M.* 3181. 1961.
Detailed investigation of the stresses in the early stator blade rows of an axial-flow compressor is described.—(33.2.4.1.10×33.1.2.×27.1).

Combined flexure and torsion of a class of heated thin wings: a large-deflection analysis. E. H. Mansfield. R. & M. 3195. 1961.
A large-deflection analysis is presented for combined flexure and torsion of solid or hollow wings of biconvex section with a parabolic chordwise temperature distribution. The analysis embraces the buckled, as well as unbuckled, regimes.—(33.2.3.1.9×33.2.3.1.2×33.2.3.1.5).

Leading-edge buckling due to aerodynamic heating. E. H. Mansfield. R. & M. 3197. 1960.
A simple formula is derived for determining the onset of leading edge buckling due to aerodynamic heating of either solid or thin-walled wings with a shear-resistant filling. Post buckling behaviour is also investigated.—(33.2.3.1.9).

The buckling of a pressurised stiffened cylinder under axial load. K. I. McKenzie. R. & M. 3198. 1961.
Buckling of a pressurised cylinder under axial load is analysed. Torsional buckling of the complete cylinder, local buckling of the stringers and pure compressive failure of the stringers are considered, and the design of stiffened pressurised cylinders is discussed, with an example.—(33.2.4.3.1×33.2.4.3.5).

Landing energy dissipation for manned reentry vehicles. L. J. Fisher. N.A.S.A. T.N. D-453. Sept. 1960.
Analytical and experimental investigations have been made to determine the landing-energy-dissipation characteristics for several types of landing gear for both parachute-supported and horizontal-landing vehicles. It appears feasible to readily evaluate these landing gears for hard-surface or water landings by computation methods and free-body landing techniques with dynamic models. Acceptable landing gear can be developed along lines similar to those presented if stroke requirements and human-tolerance limits are considered.—(33.2.3.5).

Structural behavior of pressurized, ring-stiffened, thin-wall cylinders subjected to axial compression. J. P. Peterson and M. B. Dow. N.A.S.A. T.N. D-506. Oct. 1960.
The axisymmetric mode of deformation of pressurised circular cylinders subjected to compressive end loads is examined. Stresses and deformations obtained with the theory are compared with those obtained in tests of a 7075-T6 aluminium-alloy thin-wall cylinder with high internal pressure. An application of the theory is used to explain the seemingly high buckling stresses usually obtained in bending tests of pressurised cylinders compared with those obtained in compression tests of pressurised cylinders.—(33.2.4.3×21.2.2).

Correlation of the buckling strength of pressurized cylinders in compression or bending with structural parameters. J. P. Peterson. N.A.S.A. T.N. D-526. Oct. 1960.
The data on non-pressurised cylinders in bending of N.A.C.A.

T.N. 3735 and on pressurised cylinders in compression and bending of N.A.S.A. T.N. D-360 are correlated with structural parameters using small-deflection buckling theory and reduced values for the extensional stiffness of the cylinder wall.—(33.2.4.3).

Landing-impact characteristics of load-alleviating struts on a model of a winged space vehicle. U. J. Blanchard. N.A.S.A. T.N. D-541. Oct. 1960.
Landing-impact tests were made of a 1/9-scale model of a delta-winged space vehicle landing on hard surface and on water. The use of yielding-metal shock absorbers and various landing-gear arrangements was investigated.—(33.2.3.5 × 8.2).

Analytical study of creep deflection of structural beams. L. Mordfin. N.A.S.A. T.N. D-661. December 1960.
Methods of analysing the creep deflections of beams are reviewed. The stress and strain distributions are determined for the creep bending of beams of non-rectangular cross section having unequal creep properties in tension and compression. Corrections required by transverse shear and by creep in the riveted connections are developed. The analyses are adaptable to beams made from two or more materials. The effects of shear lag on creep deflections are discussed.—(33.2.4.1.9).

Experimental investigation of creep deflection of extruded and riveted I-beams. L. Mordfin and N. Halsey. N.A.S.A. T.N. D-662. December 1960.
Aluminium alloy beams were tested in creep bending at 450° F. The creep deflections were compared with theoretical values. Examples demonstrate aspects of the bending problem, such as the effect of rivet creep on stress distribution and deflection.—(33.2.4.1.9 × 21.2.2).

Note on the design of redundant structures. E. D. Poppleton. U.T.I.A. T.N. 36. July 1960.
This note deals with the redesign of redundant structures having undesirable stress distributions. A matrix equation is derived relating specified stresses in certain structural members to changes in the stiffness distribution necessary to achieve these stresses. The equation is non-linear, in general, but can usually be solved quickly by iteration. The method of Argyris and Kelsey is used.—(33.2.1).

Experimental investigation of stability and post buckling behaviour of stiffened curved plates. A. B. T. Soderquist. U.T.I.A. T.N. 41. Sept. 1960.
Nineteen flat and curved plates having stiffeners of rectangular cross section have been tested in compression.—(33.2.4.9.1).

The telescopic strut as a beam-column. E. Kosko. U.T.I.A. Report 66. Jan. 1960.
A cantilever strut such as used in shock absorbers for aircraft landing gear is analysed taking into account the effect of lateral deflections. The concept of overlapping stiffnesses is applied to the cylinder-piston combination. As an alternative to the method of successive approximation explicit formulae are derived for a number of simple configurations and loads. A diagram is devised in which the effects of strut and support flexibility on the buckling load are combined. A numerical example shows the usefulness of the latter load in determining the bending moments.—(33.2.4.2.1 × 33.2.3.5).

A note on the use of sandwich structures in severe acoustic environments. D. J. Mead. U.S.A.A. Report 145. July 1960.
The use of sandwich structures in intense noise fields is reviewed. Related acoustic fatigue test methods are described. The tensile bond stress in a sandwich panel responding in a single mode to random pressure excitation is estimated theoretically. The principal stress on the bond is discussed, and areas of research outlined.—(33.2.4.14 × 21.3.3 × 33.1.2).

Limit analysis, limit design and linear programming. B. C. Hoskin. A.R.L. Report S.M. 274. Feb. 1960.
Both limit analysis and limit design problems for pin-jointed frames and beams are considered as special cases of the linear programming problem. The connection between the upper and lower bound limit theorems and the duality theorems of linear programming is discussed at some length. Mention is made of numerical procedures that are available for the solution of limit problems.—(33.2.2 × 33.2.4.1 × 22.1).

Investigations on the static strength of powder-powered fasteners. R. A. Fell. A.R.L. Note S.M. 267. August 1960.
Tests were made to investigate the load carrying capacity of powder-powered fasteners driven into $\frac{1}{8}$ in. structural steel plate and their effect upon the penetrated plate.—(33.2.4.13).

Stiffness tests on flat plate missile wings of rectangular planform. H. W. Galvin. W.R.E. Australia T.N. S.A.D. 15. May 1956.
A rig for stiffness tests on flat plate type missile wings is described; it measures the local chordwise rotation of the surface resulting from the application of a standard load normal to the surface. Results of tests on seven rectangular wing plan forms are given.—(33.2.3 × 33.2.3.1).

Théorie du calcul des cerces. G. Czerwenka. Pubs. Sc. et Tech. B.S.T. 126. 1961. (In French.)—(33.2.4.11).

Bending at the oblique end section of cylindrical shells. A. Van Der Neut. N.L.L.-T.R.-S.521. May 1958.
The edge bending problem at the intersection of cylindrical shells loaded by membrane stresses is dealt with. The exact solution is given for the cylindrical shell bounded by an infinite helical edge under constant edge loads. It is shown that this solution can be used to obtain a good approximation for the stresses near the actual oblique end section. The characteristics of the resultant edge loads on the shell and the loads on a reinforcing frame are discussed.—(33.2.4.3 × 33.2.4.11).

Determination of the stresses, in a not shallow spherical shell with a hole, due to an axial force, a bending moment and a transverse force. P. J. Zandbergen. N.L.L. T.R. S.518. 1958.
The stresses, occurring at the edge of a hole in a sphere, are determined if the hole is reinforced by a heavy frame. An asymptotical bending theory, developed by A. Havers, is used and reviewed. Numerical examples are included.—(33.2.4.11).

Buckling of circular conical shells under axisymmetric external pressure. J. Singer. Israel Inst. Tech. Haifa. Report 12. 1960.
The stability equation in the radial direction is rederived in a modified form similar to that given by Batdorf for cylindrical shells and is solved by the Galerkin method. Results for hydrostatic pressure are compared with those obtained by Hoff and the author in an analysis restricted to small cone angles, and with the results of other investigators.—(33.2.4.11.7).

Deformation and thermal stress in a rectangular plate subjected to aerodynamic heating. (For the case of simply supported edges.) M. Sunakawa and M. Uemura. Aero. Res. Inst. Tokyo Report 359. December 1960.
The deformation and thermal stress for a rectangular plate, subjected to an arbitrary symmetrical temperature distribution, are analysed where edges of the plate are simply supported, taking the finite deformation into account.—(33.2.4.5.9).

Compressive buckling curves for sandwich cylinders having orthotropic facings. C. B. Norris and J. J. Zahn. F.P.L. Report 1876. July 1960.
Design curves are presented for determining the axial buckling stress of sandwich cylinders having orthotropic facings and orthotropic cores. They apply particularly to those with glass-fabric laminate facings and honeycomb cores. Sandwich construction with isotropic cores are included.—(33.2.4.14.1 × 33.2.4.3.1 × 21.2.3 × 21.3.6).

Compressive buckling curves for flat sandwich panels with dissimilar facings. C. B. Norris. F.P.L. Report 1875. Sept. 1960.
Curves and formulae for calculating the buckling of flat, simply-supported panels of sandwich construction under edgewise compressive loads are presented. The curves apply particularly to sandwich panels having one facing of glass-fabric laminate, the other of an isotropic material, and a honeycomb or isotropic core.—(33.2.4.14.1 × 21.2.3 × 21.3.6).

TESTING

The fitting of damped sine-waves to data. D. G. Ford. A.R.L. Note S.M. 264. Feb. 1960.
Two methods are given for fitting damped sine-waves to measure data which include the estimation of frequency and damping constants. A numerical solution of the normal equations is outlined and the testing of hypotheses concerning parameters of several waves, including frequency and damping, is discussed.—(33.3.2 × 22.1).

WEIGHT ANALYSIS AND CONTROL

The design of Michell optimum structures. A. S. L. Chan. C.o.A. Report 142. Dec. 1960.
The fundamental problem of structural design is the determination of structures of minimum weight which safely equilibrate a given system of external forces. The geometrical layout of

two-dimensional structures which satisfy these requirements are analysed first, using the analogy with the theory of plane plastic flow. Expressions for the calculation of sizes and the total volume of the structural members are developed. Method of graphical construction of the structural layout is given. The analogy with a known solution of plastic flow is used to develop solutions for a cantilever under tip shear force and a beam under uniform bending moment. Comparisons with conventional constructions are made and the superiority of the Michell structures demonstrated.—(33.4.1 × 33.2.2 × 33.2.4.1).

THERMODYNAMICS

See also SCIENCE—GENERAL

The theory of thermo-gravitational convection in turbulent conditions. L. E. Ber. R.A.E. Lib. Trans. 920. *Oct.* 1960.
Approximate equations describing the superposition of turbulent constrained convection and free thermal convection have been obtained. The "turbulent viscosity" and "turbulent conductivity" which made up the equations were studied for a flow in a circular cylindrical pipe by processing the experimental data of a number of authors. The problem of the superposition of turbulent constrained convection and free thermal convection in a circular vertical pipe is solved approximately. Results are compared with experiments.—(34.3.2).

Thermodynamic charts for the decomposition products of 80, 85 *and* 90 *per cent w/w hydrogen peroxide. E. Carter. R. & M.* 3158. 1960.
Themodynamic charts showing enthalpy, entropy and specific volume for a range of pressures and temperatures have been constructed for the decomposition products of 80, 85 and 90 per cent w/w hydrogen peroxide (H.T.P.) for regions above and below the saturation line. Examples are given to show how gas velocity, venturi nozzle throat and exit areas, exit pressure, specific heat at constant pressure, γ, characteristic velocity and thrust coefficient can be deduced from the charts and the rider scale enclosed with this paper.—(34.1 × 27·3 × 14).

Alignment charts for transport properties viscosity, thermal conductivity, and diffusion coefficients for nonpolar gases and gas mixtures at low density. R. S. Brokaw. N.A.S.A. T.R. R-81. 1960.
Alignment charts (nomographs) designed to permit rapid calculations of the low-pressure transport properties of nonpolar gases and gas mixtures are presented. Calculations for pure gases are based on the rigorous kinetic theory of gases as applied to a realistic intermolecular force law. Mixture viscosities and conductivities are calculated from good approximations derived from rigorous theory. Force constants are tabulated for 65 gases.—(34.4).

Empirical equation for turbulent forced-convection heat transfer for Prandtl numbers from 0·001 *to* 1,000. *U. H. von Glahn. N.A.S.A. T.N. D-*483. *December* 1960.
An empirical equation is evolved which yields fully turbulent forced-convection heat transfer in smooth tubes for a Prandtl number range applicable to Newtonian fluids from liquid metals to viscous oils. The equation is based on selected analyses and experimental data available in literature.—(34.3.3 × 27.6).

*The dielectric bolometer, a new type of thermal radiation detector. R. A. Hanel. N.A.S.A. T.N. D-*500. *Nov.* 1960.
Thermal detectors for the infra-red, such as thermo-couples and bolometers, are limited in their ultimate sensitivity predominantly by Johnson noise rather than temperature noise. The dielectric constants of some materials are sufficiently temperature dependent to make a new type of bolometer feasible.—(34.2).

*Comparison of theoretical and experimental values for the effective heat of ablation of amonium chloride. J. E. Welker. N.A.S.A. T.N. D-*553. *Nov.* 1960.
Thermodynamic properties of ammonium chloride have been obtained and applied to a theoretical analysis of the shielding mechanism which reduces the rate of heat transfer to a body when ablation takes place at the surface. The analysis considered the mechanism as one in which the material sublimes directly from the solid to the vapour phase. Results of the computation are compared with experimental results from the Langley 700-kilowatt arc jet.—(34.3 × 21.3).

*Effect of shield position and absorptivity on temperature distribution of a body shielded from solar radiation in space. L. D. Nichols. N.A.S.A. T.N. D-*578. *January* 1961.
Temperature distributions on two discs subjected to solar radiation are analysed and the effect on the temperature distribution of absorptivity, thermal conductivity, and the spacing between discs determined.—(34.3.1 × 8.2).

*An investigation of a photographic technique of measuring high surface temperatures. J. H. Siviter and H. K. Strass. N.A.S.A. T.N. D-*617. *November* 1960.
A photographic method of determining elevated temperatures of surfaces is given. The investigation gives a simplified technique of calibrating a photographic emulsion.—(34.2).

*On the evaporation and decomposition of droplets of liquid ozone oxygen mixtures in a hot oxygen atmosphere. R. Sandri. N.R.C. Report MP-*19. *December* 1960.
Evaporation rates and lifetimes of droplets of a 50-50 mole per cent ozone-oxygen mixture in a hot oxygen atmosphere at 20 atmospheres pressure were calculated by electronic computers under the assumption that the temperature and concentration fields were in a quasi-steady state and that the interior of the liquid was at a uniform, constant temperature except in a thin layer adjacent to the surface.—(34.1.1 × 34.4).

*Low temperature operation of a catalytic combustion heater. T. R. Ringer. N.R.C. Report M.D.-*46. *Oct.* 1960.
Starting and operating tests using two fuels were conducted on a catalytic heater over a temperature range from +70°F to −60° F.—(34.1.1 × 14).

Film boiling on hydrodynamic bodies. W. S. Bradfield et al. *Convair Sc. Res. Lab. Note* 37. *Dec.* 1960.
Free and forced convection quenching studies of hydrodynamic shapes are presented. Effects of subcooling and surface condition on heat flux and vapour layer stability are included. Motion picture studies of characteristics of vapour-liquid interface configurations are discussed. These include vapour layers generated by sublimation and with a chemically reacting surface in combination with film boiling. Forced convection heat transfer and friction drag measurements in water are compared with theoretical predictions.—(34.3.2 × 34.3.4 × 17.1).

*Experimental examination of local processes in packed beds of homogeneous spheres. Part I. The local packing in randomly stacked sphere beds. Part II. The local heat transfer over the surface area of a sphere immersed in a packed bed of infinite dimensions and arranged in rhombohedral array. J. Wadeworth. N.R.C. Report M.T.-*41. *Feb.* 1960.
Part I: The local packing in cylindrical containers when randomly stacked with homogeneous spheres is examined from 4 to 24 of the ratio of container diameter to sphere diameter. Sphere packings are examined both as a function of radial and vertical position in the bed. Part II: A three-dimensional picture is given of the heat transfer over the surface area of a sphere immersed in a packed bed of "infinite" dimensions for Reynolds numbers of 8,000 to 60,000, where *Re* is based on sphere diameter, average velocity of the coolant across the cross-section of the bed in the absence of the spheres, and fluid properties evaluated at the mean film conditions.—(34.3 × 1.9.1).

Étude expérimentale de la convection de la chaleur dans un canal avec profils de vitesse variables. J. J. C. Picot. Pubs. Sc. et Tech. N.T. 94. 1960. (*In French.*)—(34.3.2).

Détermination par la "méthode inverse" des caractéristiques des ondes explosives. N. Manson. Pubs. Sc. et. Techs. 366. (*In French.*)
From the classical hydrodynamic theory of detonations, it is possible to deduce relations giving the thermodynamic characteristics of burnt gases when the speed of an explosive wave and certain thermo-elastic properties of the explosive (gaseous or condensed) are known. Examples applied to two gaseous explosive mixtures and an explosive liquid are given and possibilities of the method examined.—(34.1.1 × 17.1 × 1.2.3.2).

Contribution a la détermination des limites d'inflammabilité des hydrocarbures. N. Sivolobov. Pubs. Sc. et Tech. 370. 1960. (*In French.*)—(34.1.2).

NOTE—Most of the reports listed are available on loan to bonafide inquirers, but the Society is not agent for the sale of any of them. The great majority of the reports are "unpublished" and are not, therefore, obtainable through booksellers or other agents. Notable exceptions are the R. & M. and C.P. series which can be bought through Her Majesty's Stationery Office.